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Assessment of Pinyon and Juniper derived biochar as a soil amendment to increase survival of urban trees in Nevada

A report presented to the Nevada Division of Forestry

Dr. Casey Schmidt
Desert Research Institute
Division of Hydrologic Sciences
2215 Raggio Parkway
Reno, NV 89511

Executive Summary

Due to fire suppression and other factors, Pinyon and Juniper (PJ) (*Pinus monophylla; Juniperus osteosperma*) woodlands are encroaching outside of their normal range resulting in a demand for thinning and fuels reduction projects. There is little economic benefit from this woodland type and hence limited funding to further these projects. State and federal agencies have begun evaluating the potential of producing a marketable biochar soil amendment to overcome these obstacles. Biochar is produced from smoldering combustion, which produces a long-lasting form of organic carbon that has a high reactive surface area. When applied as a soil amendment it has the potential to provide benefits to foresters, homeowners, gardeners, and horticulturalists. Urban trees provide significant aesthetic, health, and environmental benefits yet due to limited fertilization, maintenance, and irrigation, mortality rates of urban trees are high. In this project, we evaluated whether biochar can improve the livelihood of urban trees.

Through lab and greenhouse studies we determined if the benefits of PJ biochar are factual and significant, and provided specific models where possible on how to process and apply biochar. Specifically, we evaluated the potential of using Pinyon-Juniper biochar as a soil amendment to increase plant available water, soil fertility, and plant health. Depending on the goal of biochar application in soils, we provided tailored advice for application. Based on this project, it is clear that if biochar is correctly applied it will add demonstrated value as a soil amendment.

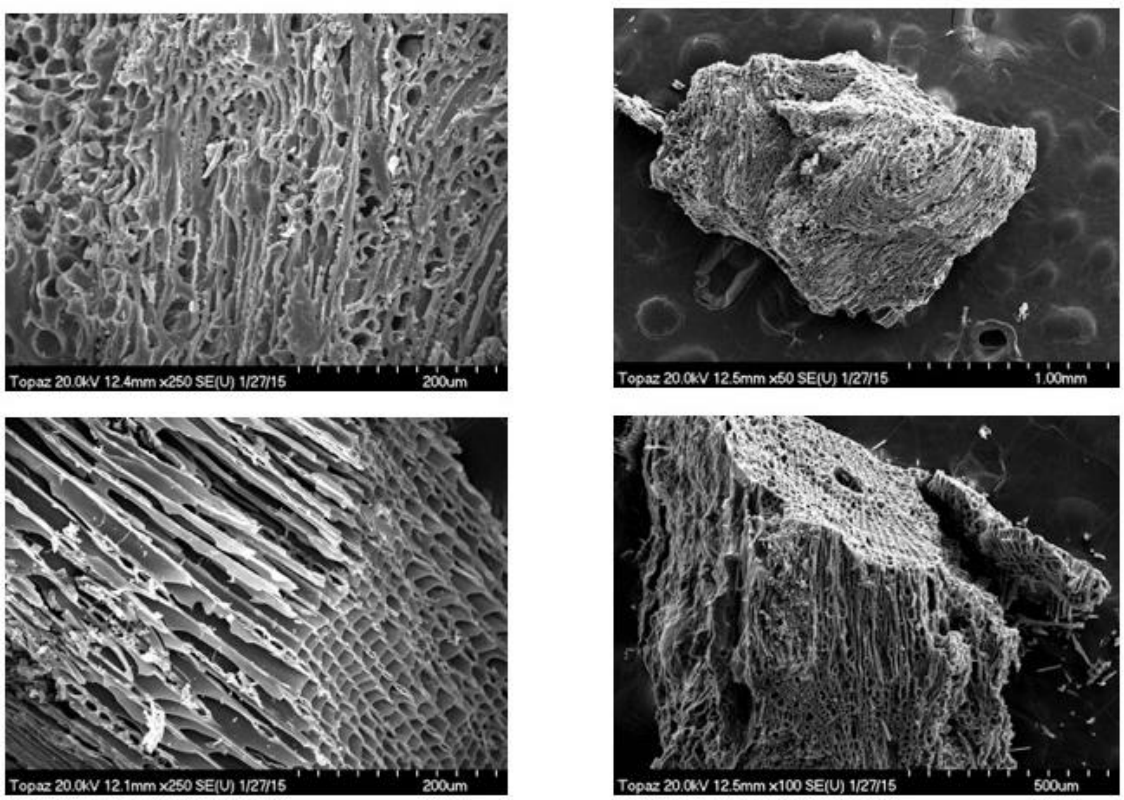
The most significant benefit to biochar application resulted from the ability of this media to increase soil fertility. Nitrogen concentrations of biochar mixes increased by an order of magnitude, and phosphorus leaching was significantly mitigated by biochar. This indicates that biochar can be utilized in urban tree plantings where fertilization will be minimal. Biochar can increase plant available water thus reducing irrigation requirements, although this was most predominant when biochar was amended to organic nursery potting mixes and in clay soils. In sandy and silty soils increases in plant available water occurred only at the highest biochar applications and using biochar of a very small particle size. Biochar provided some improvement to plant health especially when applied to match the water requirements of the plant. Through this project, we evaluated a composted biochar produced by Great Basin Organics, a commercial soil producer. The composting process increased the soil moisture content and provided significant benefits in terms of soil fertility. Photosynthesis did increase when biochar was added, although the composting process added no further value.

Furthering the biochar market requires closing knowledge gaps around production costs, efficiency, and air quality impacts. Increasing the market for biochar involves continued education on biochar benefits and the correct methods for application. This document should provide guidance and education on the continued use of biochar.

Assessment of Pinyon and Juniper-derived biochar as a soil amendment to increase survival of urban trees in Nevada

Introduction and Background

The Nevada Division of Forestry (NDF) has furthered pilot studies related to the development of biochar from underutilized Pinyon-Juniper (PJ) woodlands (*Pinus monophylla; Juniperus osteosperma*) through the purchase of ten transportable metal kilns. Biochar is generally defined as a product of smoldering combustion, thermal degradation, and pyrolysis that results in a form of organic carbon that has a high surface area and is resistant to degradation. Practically speaking, biochar is charcoal that is used for the purposes of soil remediation, filtration, and as a soil amendment in agriculture. The result is a form of organic carbon that is long-lived in the soil whether it is applied in sage restoration sites, urban parks, or suburban gardens and that may impart benefits related to soil fertility and plant available water.



Scanned Electron Micrograph of Pinyon Juniper biochar produced by the NDF kiln

A novel application of biochar that is evaluated in this project is the use of biochar in urban areas. Urban forests provide numerable pragmatic, aesthetic and health benefits to the public. These forests are exposed to pressures that are unique from other forests because they have a limited soil and rooting area, increased soil compaction, high contaminant concentration, as well as limited irrigation and fertilization. As outlined here, we evaluated the potential of PJ biochar in ameliorating some of these impacts.

Furthering the use of PJ biochar in to a marketable product for urban trees and other uses requires resolving multiple uncertainties related to the production, processing, and application of this material (Table 1). The cost of biochar production can vary significantly depending on how it is produced, how it is processed, and how it should be applied for its intended use. Additionally, the market for biochar involves quantifying the actual benefits of biochar application to justify costs, and to provide label-ready information. If a homeowner, farmer, or nursery manager can't feel confident that this soil material will help them grow plants, then they won't pay a premium price for biochar amended soil. There is scant information on the application and actual benefits of PJ biochar that can inform the development of this market. Much of the information on the use of PJ biochar as a soil amendment has been gleaned from biochar produced from other wood, and based on general theories of soil properties without actual data to support these conclusions.

Table 1 – An outline of the uncertainties in biochar development. Some of these uncertainties were definitively assessed in this project, while others still need to be resolved.

	Uncertainties	**Market implications**
Biochar Production	• Type of biochar produced by NDF kiln, • Cost to produce, • Amount of biochar produced per amount of PJ cleared, • Air quality impacts & carbon release and storage	• Can biochar produced in PJ woodlands be cost-effectively brought to market • What are the externalities in production to consider
Biochar Processing	• What particle size should be used? • Should biochar be composted?	• Production of fine particle sizes can be costly • Composting can be costly
Biochar Application	• How much biochar to add? • Does biochar add any value?	• The amount of biochar needed to produce a benefit feeds back in to production costs and the cost per bag • Quantifying the benefit of biochar as a soil amendment facilitates label-ready information that defends cost premiums.

The Nevada Division of Forestry has focused their production on metal kilns because they match their requirements of transportability, ease of use, safety from unintended fires, and the ability for the kilns to remain unmonitored overnight. The Desert Research Institute (DRI) evaluated the production of biochar using these kilns, although there is still further knowledge to be gained on the air quality impacts of production using this method. Another unknown is related to the processing of biochar. The biochar produced by these kilns generally consists of a large variety of materials from thermally degraded whole sized branches to fine material that can be mobilized in to the air and lungs. The processing costs will vary significantly depending on the particle size of biochar that produces the most significant benefits and therefore we placed a careful emphasis in this project on the influence of biochar particle size. Another aspect of production centers around the interest in composting biochar so that it can be 'activated' with beneficial soil microbes and potentially stabilize and reduce some of the negative aspects of biochar (e.g. alkalinity, sterility). Lastly, foresters, urban gardeners, and others need straight-forward advice on how biochar is to be applied including how much, what particle size, and the expected benefit of application. We discovered that the benefits of PJ biochar application were variable, although as best as possible we tried to provide specific, and pragmatic advice for the application of biochar throughout this document.

The format of the document involves firstly assessing the production of biochar and the product produced by the NDF kiln and discussing what remains to be known. Next, we focus on the use of biochar as a soil amendment to influence the amount of water available to plants in arid environments and the potential for biochar to enhance soil fertility. Furthermore, the tangible influence of biochar on tree growth and health is evaluated. Lastly, we discuss what remains to be known and what the future holds for biochar. To focus the reader's attention we have generally placed most detailed information on the project methods in the appendix for those who require further information.

Pictures of the biochar production process using the NDF kiln.

Biochar Production

The Nevada Division of Forestry has focused their biochar production on a metal kiln because it is transportable, safe, and easy to use. In order to evaluate this biochar production method, we need to understand the rate at which wood can be processed, the amount and properties of biochar being produced, and the properties of the smoke emitted. In this project, we evaluated the properties of the biochar produced by the kiln, the amount of biochar produced in the kilns, and the potentially sequestered carbon produced by the kiln.

Biochar Production and Carbon Sequestration

It is complicated to measure the amount of wood loaded in to a large kiln packed heterogeneously with wood of various sizes, and quantify the amount of biochar that is produced. Therefore, the relationship between the amount of Pinyon and Juniper wood that can be utilized to produce a resulting amount of biochar was evaluated using two methods that are described in Appendix 1. The two measurement methods tend to be in good agreement (Figure 1). Each kiln can be loaded with 2,170 – 2,600 lbs. of wood and produce approximately 664 lbs. of biochar which reduces the mass by 69 – 74%, and the volume by approximately 65%. The remainder is released to the atmosphere in various forms (i.e. particulates, gasses). Each kiln burn releases approximately 1,145 – 1,309 lbs. of carbon to the atmosphere in various forms (i.e. long to short chain C molecules, methane, carbon dioxide, carbon monoxide), while preserving approximately 157 lbs. of potentially sequestered carbon in the form of biochar for every 48 hour burn.

Conclusions and Further Work

Further analysis is necessary to scale these assessments to an operational level, although the results here provide a good framework for that work. Based on the values shown here it is possible to determine the acreage of Pinyon-Juniper woodlands that can be cleared as compared to cost and the amount of biochar produced. Another component that is missing from this work is an evaluation of the atmospheric release when biochar is produced. Based on these results, we know that a significant amount of carbon and other constitutents of potential air quality concern are released. The health impacts and warming potential depend on the forms of smoke, gas, and particulates that are released. Further work is necessary to determine this. It is important to note that biochar production should be compared to status quo methods of PJ thinning including chipping, pile burning, or a do-nothing option with an increased potential for catastrophic wildfires. Therefore, the large amounts of atmospheric release need to be taken in to context.

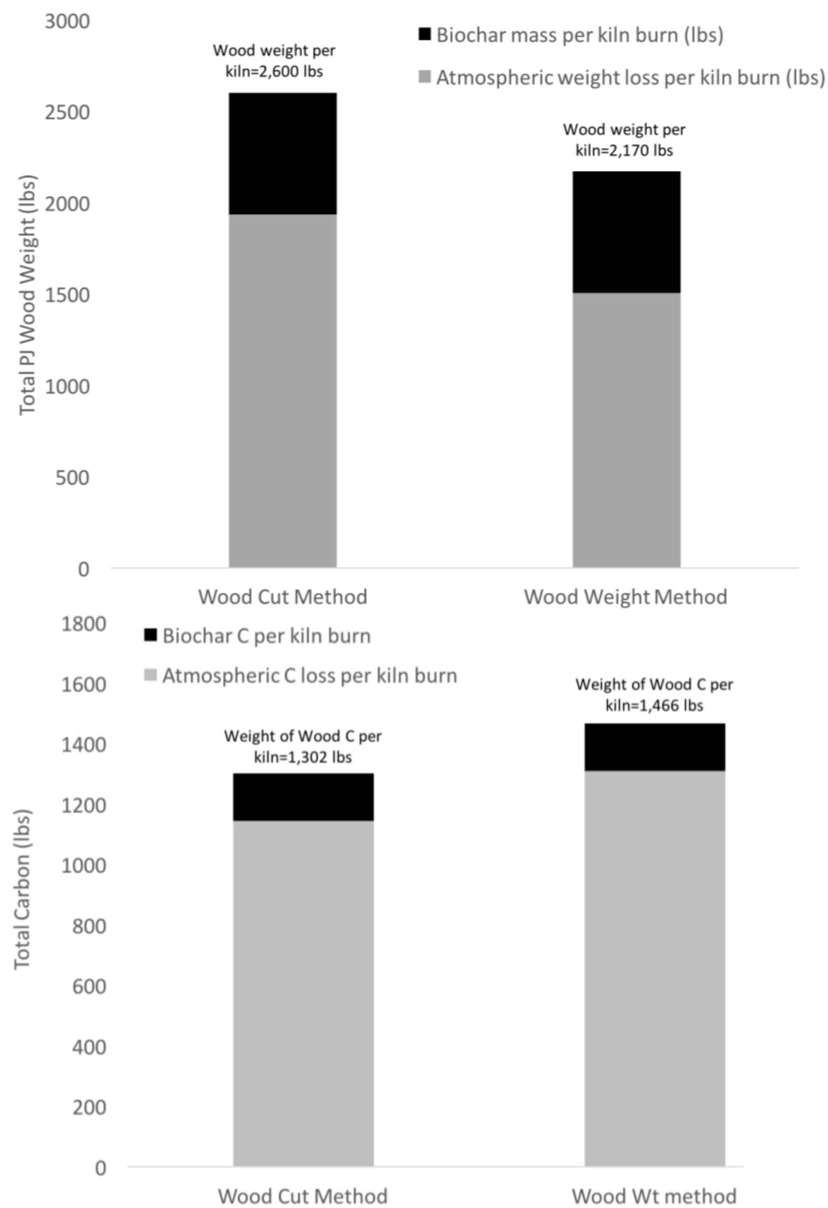


Figure 1 – Shown in the figure are the amount of carbon (bottom) and total weight (top) of the wood, the biochar, and the amount that is released to the atmosphere in various forms (i.e. particulates, gasses).

Biochar Properties

The goal of this project is to determine the potential benefits of utilizing biochar as a soil amendment to improve plant health and survival. Therefore, we evaluated the essential plant nutrients that are present in the biochar, and potential physical and chemical factors that can influence plant survival (e.g. pH) and nutrient retention (e.g. Biochar surface area). A limitation to the transportable kilns that NDF uses is that there is no temperature control. Previous studies have found that the production temperature of biochar plays a significant role in the properties of biochar. Through previous work and in the present project we evaluated the properties of the NDF produced biochar and compared to biochar produced under temperature controlled conditions at 350, 500 and 700° C (Appendix 1). Biochar produced in the kiln varies across the entire range of these temperatures (Figure 2), and it is important to discern the influence of biochar production temperature, and how comparable the NDF biochar is to biochar produced under controlled temperatures.

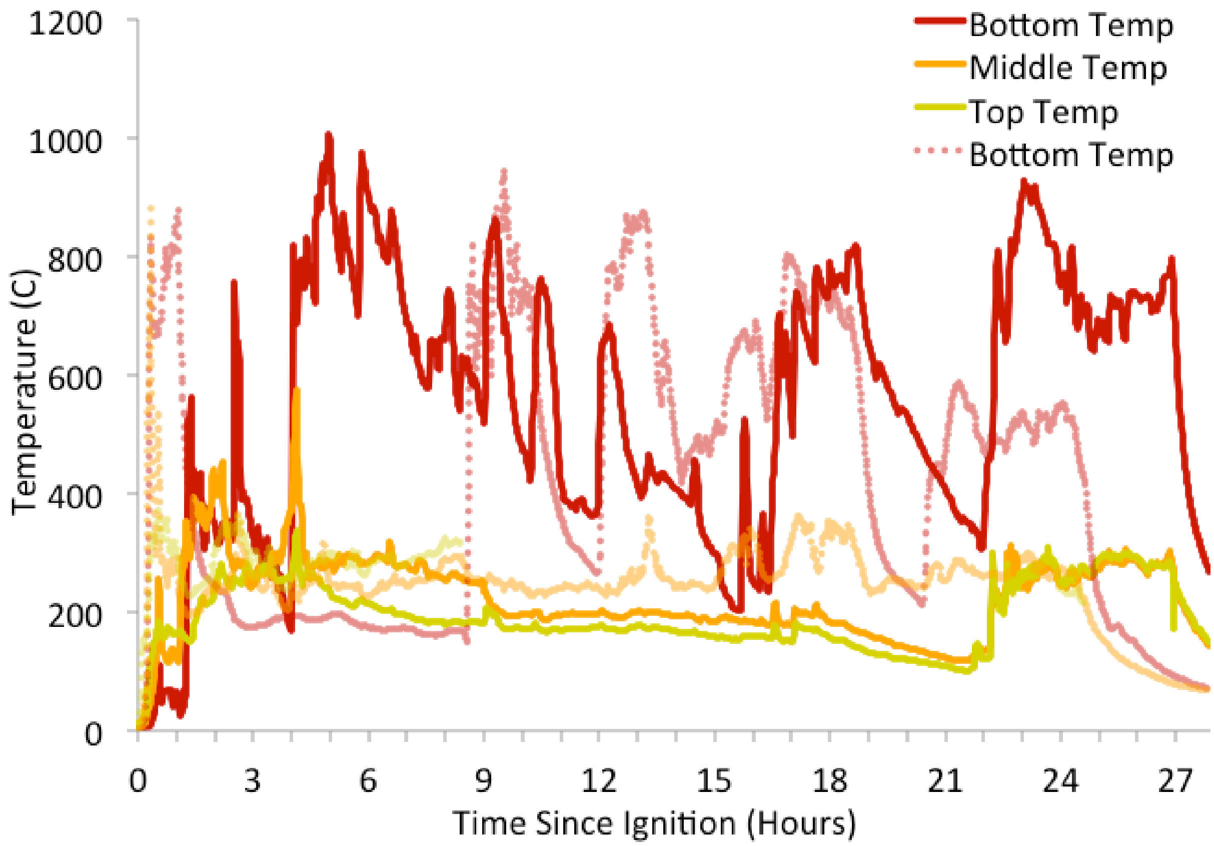


Figure 2 – The production temperature over time at different locations in the NDF transportable metal kiln. The temperature is highly variable, therefore it is important to compare the biochar produced by NDF to biochar produced under controlled temperatures.

One of the potential benefits of biochar is a high reactive surface area that facilitates nutrient retention and the use of biochar as a filtration media. It is clear that the surface area of biochar dramatically increases when production temperature increases above 500°C, therefore it is important that biochar production temperatures exceed this threshold (Figure 3). The surface area of the NDF kiln-produced biochar is highly variable, and has an intermediate area between high and low production temperatures inherent to the variable kiln temperatures observed.

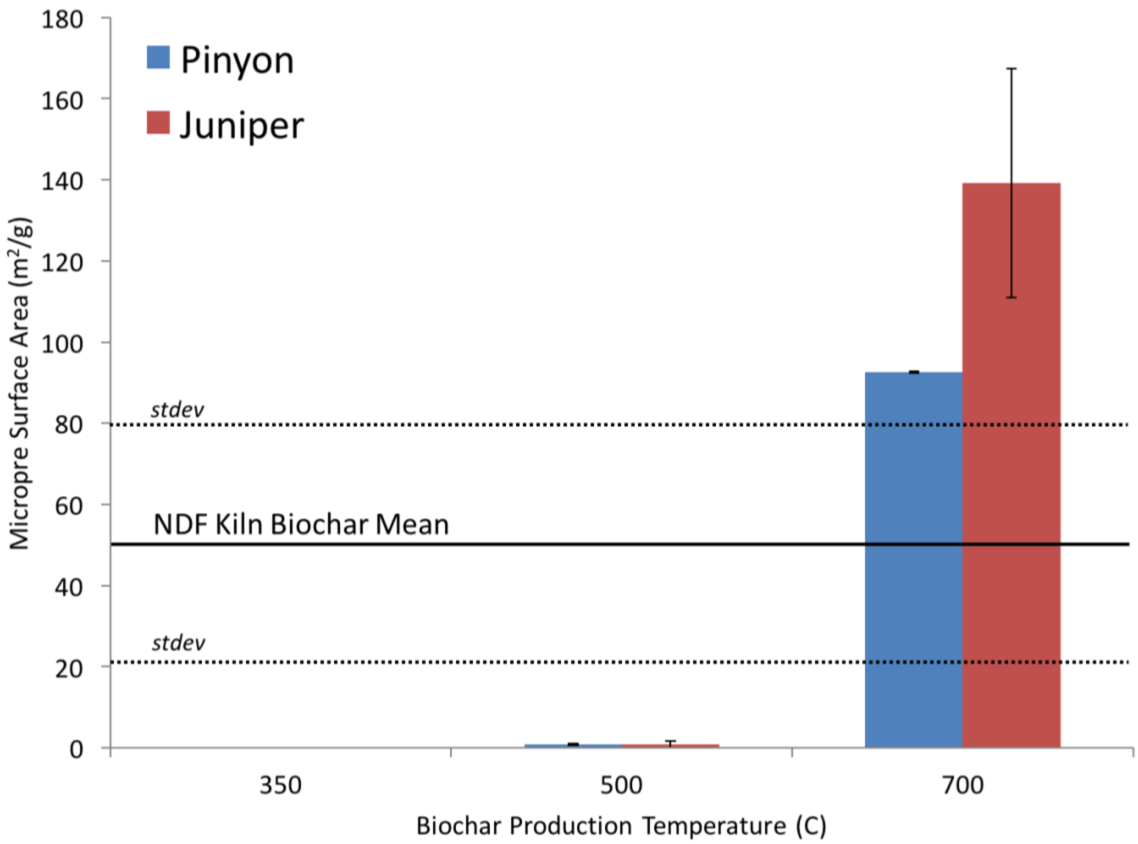


Figure 3 – In this figure is shown the surface area of NDF kiln-produced biochar, and biochar produced under controlled conditions. The surface area of biochar produced in the NDF kiln is indicated as a straight line with standard deviation lines.

The concentration of essential plant nutrients and the pH of the different biochar types are shown in Figure 4. As expected, higher biochar production temperatures tend to concentrate nutrients that volatilize at higher temperatures, while decreasing the components that are released in the smoke. Potassium, Magnesium, and Calcium are concentrated in higher temperature biochar, while nitrogen and phosphorus increase somewhat until the temperature increases above the volatilization temperature of the nutrient. The kiln-produced biochar tends to have very high concentrations of potassium, magnesium, phosphorus and nitrogen as compared to the highest temperature biochar, while the calcium is low, and the pH is generally at the alkaline end of the range.

Although the production temperature of the NDF kiln is highly variable, by most metrics measured (i.e. surface area, plant nutrients) the NDF biochar compares favorably with the biochar produced under controlled production temperatures. This alleviates some concerns related to the quality of the biochar produced by the relatively simple NDF kiln.

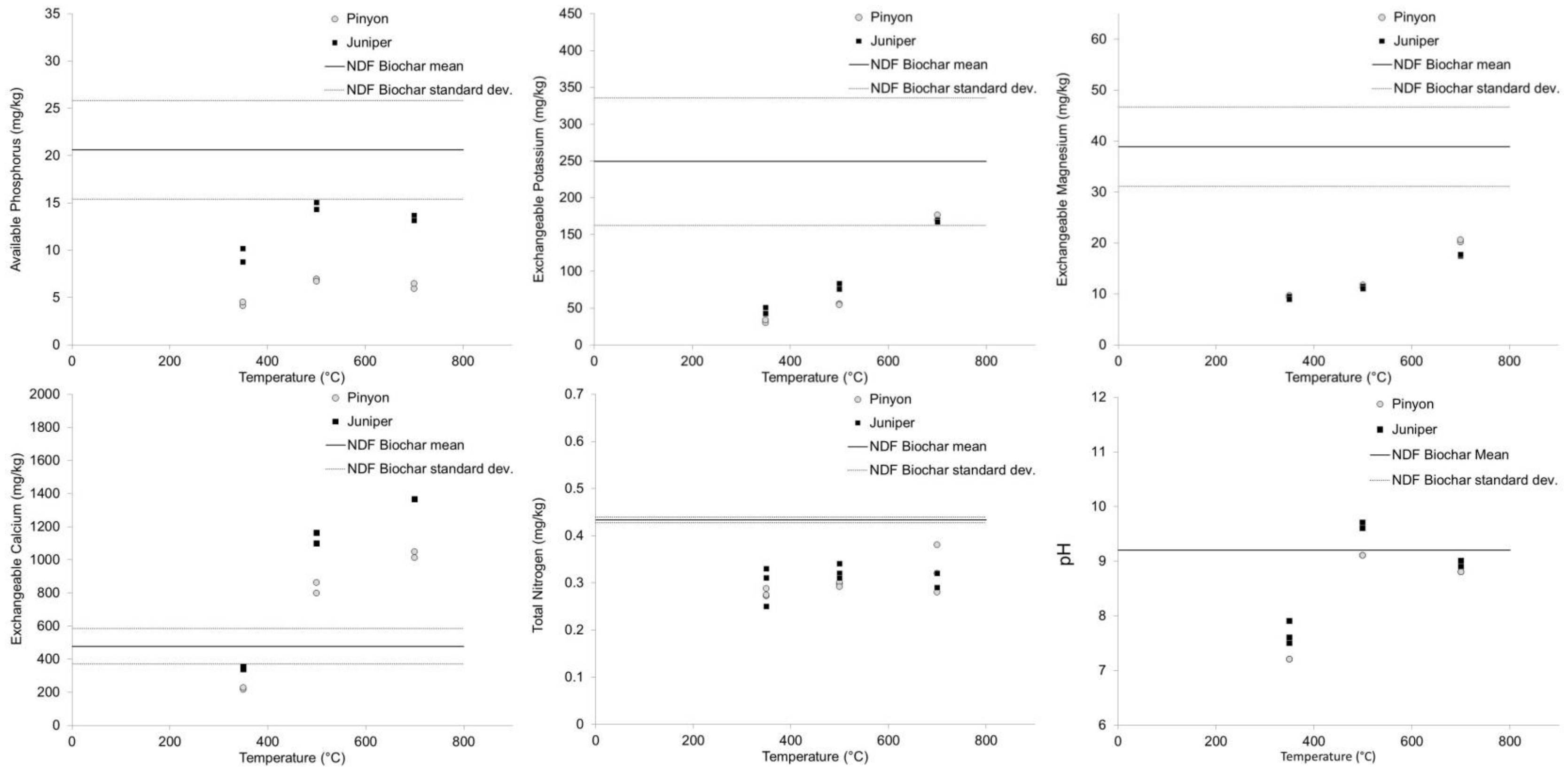


Figure 4 – The concentrations of essential plant nutrients and pH of biochar NDF kiln-produced biochar, and biochar produced under controlled production temperatures.

Biochar as a Soil Amendment

There are two levels of guidance that are necessary to further the use of biochar in Nevada. At the production level, Nevada Division of Forestry staff and commercial producers need to know the details of the biochar they produce. The second level of guidance centers around the homeowner, forester, and urban gardener who is in need of tailored advice on the benefits of biochar, and how best to apply the soil amendment. Adding biochar to a particular soil or nursery potting mix is not recommended until a particular biochar type is evaluated and recommendations are developed on the correct application amounts, and the production and processing methodology. In the following section, we evaluate the potential of these different biochar applications to influence soil properties that are beneficial to promoting tree growth including plant available water, and increased soil fertility.

Moisture Retention

Similar to other organic soil media, biochar has the potential to influence soil water holding capacity, plant available water, and drainage. Given the drought-stress on urban trees in arid regions, it is important to evaluate and customize biochar application in order to maximize plant available water. Soil hydraulics can be strongly influenced by the particle size and amount of biochar added to soil/media. For instance, a clay soil is composed of very small soil particles and therefore it is poorly drained and holds water tightly, while a sandy soil is composed of large soil particles and dries out more rapidly. Therefore, we evaluated different biochar application amounts and biochar particle sizes in this section and throughout the document. The influence of biochar on plant available water was evaluated through controlled lab studies on biochar mixes with four different soil types in order to tailor applications to soils across Nevada, and in the greenhouse to evaluate the role of biochar in potentially reducing irrigation requirements in nurseries.

Plant Available Water in Nevada soils with biochar

The water available to plants is dependent on the total moisture content after irrigation/rainfall/snowmelt, as well as the tension with which the water is held to soil. For instance, a clay soil may have a high water content after irrigation/rainfall, but the water may be held too tightly to soil particles for plants to access, while a silty soil may have a lower total water content although the water may be more available to plants. Therefore, simple measures of total soil moisture are insufficient, and a more detailed assessment of plant available water is necessary.

It is expected that urban foresters, homeowners, and ranchers across the state will be interested in adding biochar to many different soil types. There is little information on how much biochar to add for a given soil type, and it is highly likely that there will be variability in the influence of biochar on different soils. Biochar was mixed with a nursery potting media developed by the Nevada Division of Forestry Washoe Nursery (Appendix 1), and three soil types found in large portions of Northern and Southern Nevada from sands to finer soils (Figure 5). These soil types include the Orovada series, which is the state soil located in an agriculturally important region, the Settlemeyer series which is a silty soil that encompasses much of Reno/Carson City and the region around the Truckee river, and an Arizo series that is a sandy soil surrounding Las Vegas and Henderson (Figure 6). The biochar was mixed in four amounts (0, 5, 15, and 30% mass of biochar/mass of soil) with each of the soil types, and 8 different particle sizes were used. The soil-biochar mixes (Figure 5) were saturated and through detailed experiments (Appendix 1), the total plant available water was determined.

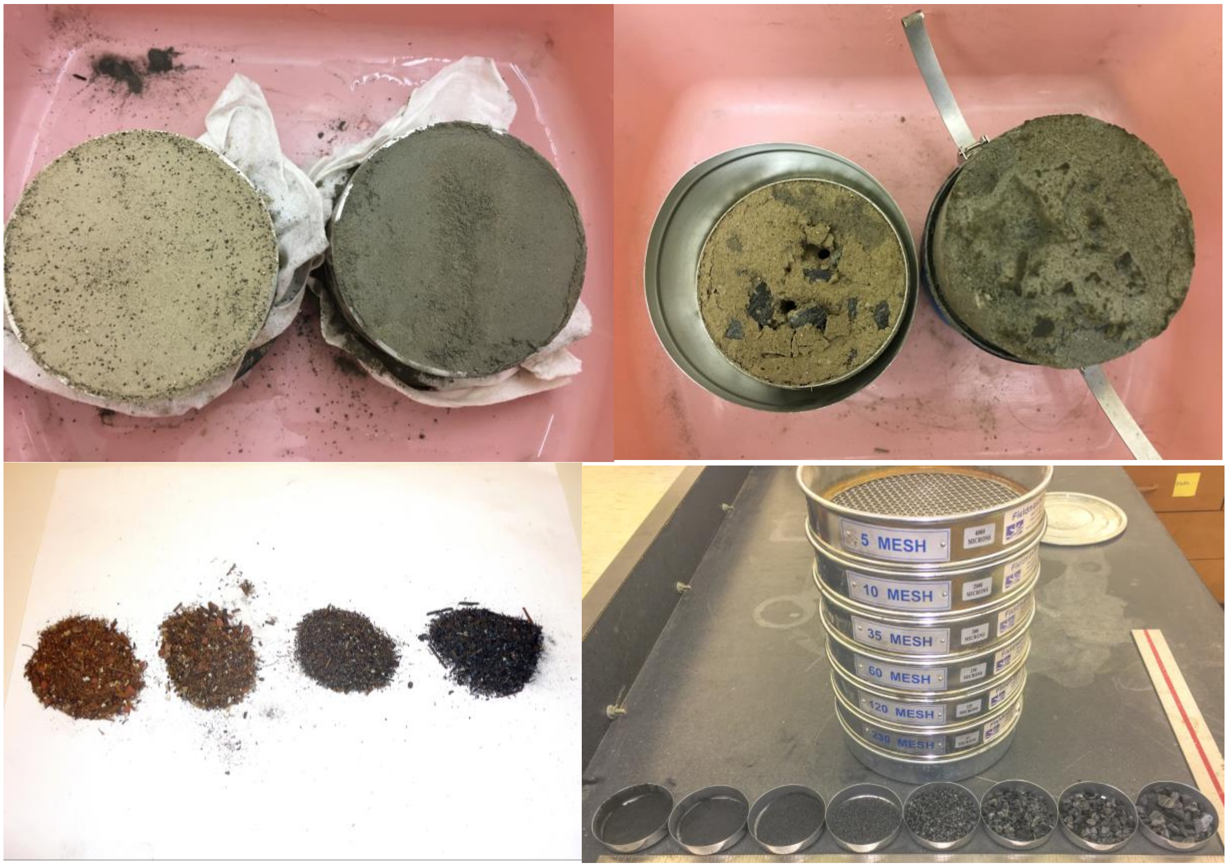


Figure 5 – Pictures demonstrating the structural differences of adding different amounts and particle sizes of biochar, as well as images detailing the methods for the project. Shown in the top row is the set-up used to determine plant avaiallble water with a scale and pressure transducers at two different locations and a close-up of a soil core showing the porespace where water is stored. The second row shows the soil and biochar before and after mixing. The third row shows cores with different biochar amounts and particle sizes. The last row shows mixes with different amounts of biochar bottom left, and the different biochar particle sizes in the bottom right.

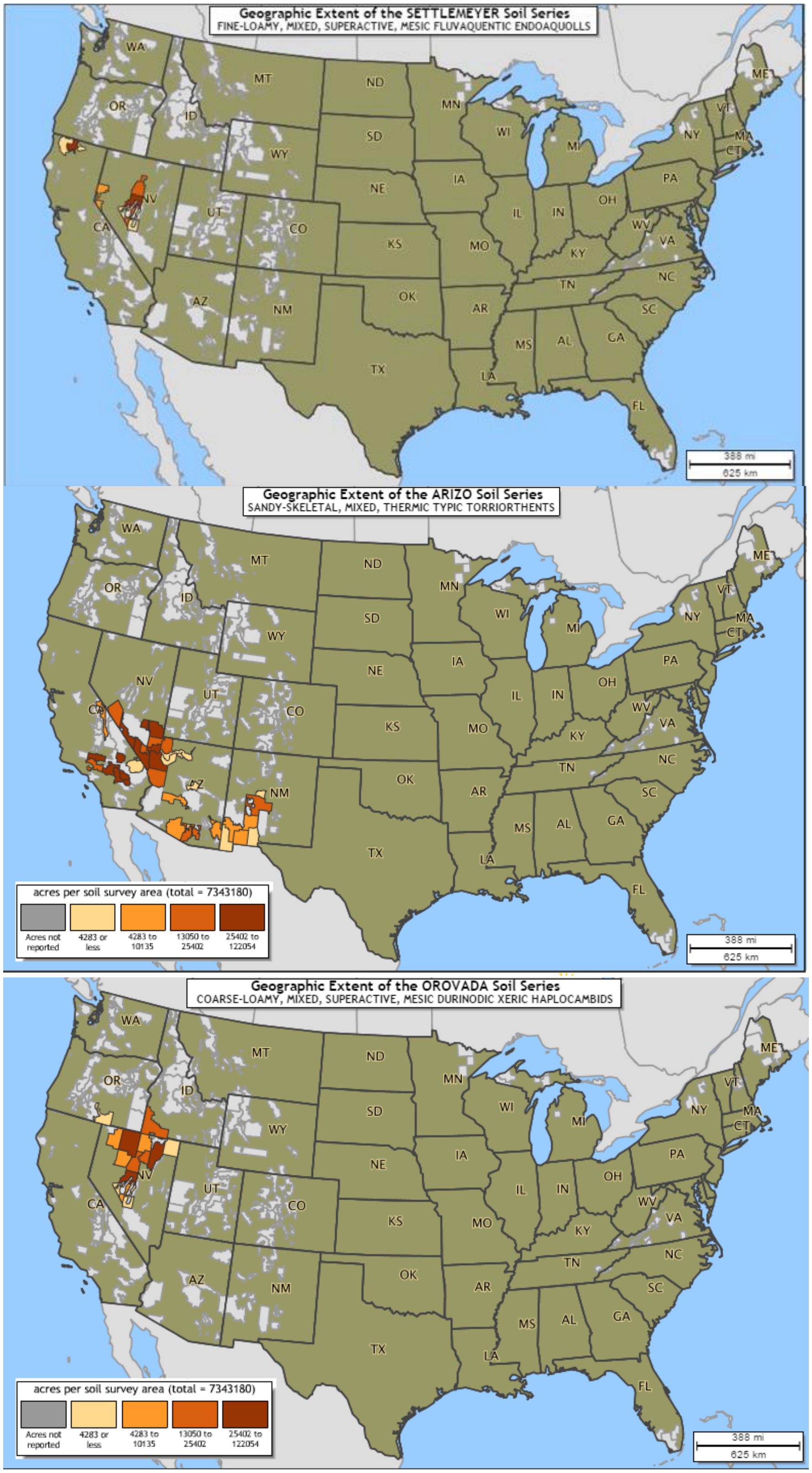


Figure 6 – Shown in the figure is the geographic extent of the three soils used in the soil moisture and plant available water project including the clayey Settlemeyer soil (top), a sandy Arizo soil (middle), and a silty Orovada soil (bottom).

The format of much of this document will center around two separate but overlapping assessments that include firstly a comparison of the different biochar applications to a control soil/media with no biochar to determine if there is any added benefit, and a separate analysis of whether biochar amount and particle size are important to guide biochar processing and application. For this latter analysis, a statistical tool called a multiple linear regression was used. This method assesses general trends in datasets and allows for a determination of whether biochar particle size and amount play a role, and subsequently produces a model of the data so that specific, easily-interpreted guidance can be given on the influence of biochar application.

When biochar was added to the NDF nursery potting mix, the sandy Arizo soil, and the clayey Settlemeyer soil, increasing the amount of biochar significantly increased the plant available water (PAW). Additionally, there was a negative trend with biochar particle size, indicating that smaller biochar increases PAW more. For the silty Orovada soil, the biochar particle size and application amount had no consistent influence on plant available water. Using multiple linear regression, the data was modelled to provide expected plant available water for different biochar applications (Figure 7).

When comparing biochar-amended potting soil to the control potting soil, the plant available water generally only increased when ultra-fine biochar (<0.09 mm) was mixed with the media particularly at higher application amounts of biochar (15-30%) (Figure 8). Most other biochar treatments had equivalent amounts of available water to the control. This indicates that if biochar is to be utilized as a nursery soil amendment in order to reduce irrigation requirements, then it needs to be applied in high quantities and small particle sizes. In the sandy Arizo soil, there was no consistent increase in plant available water above the unamended soil, except possibly at fine particle sizes and high applications (Figure 9). Many of the 5-15% applications at larger particle sizes (<3 mm) actually decreased the plant available water from the control sand soil. This indicates the limited utility of utilizing biochar to increase plant available water in sandy soils. In the silty Orovada soil, the only increase in plant available water occurred in ultra-fine biochar (<0.03 mm) and at an application of 30%, while all other biochar applications were equivalent (Figure 10). The most consistent increase in plant available water and occurred in the clayey soil (Settlemeyer), although as with the other soils the PAW increase was most significant in high biochar application amounts and fine particle sizes (Figure 11). It is possible that this results from the fact that biochar breaks up the strong surface tension in clay soils that deprives plants of water. This indicates the utility of using biochar to increase plant available water in clayey soils.

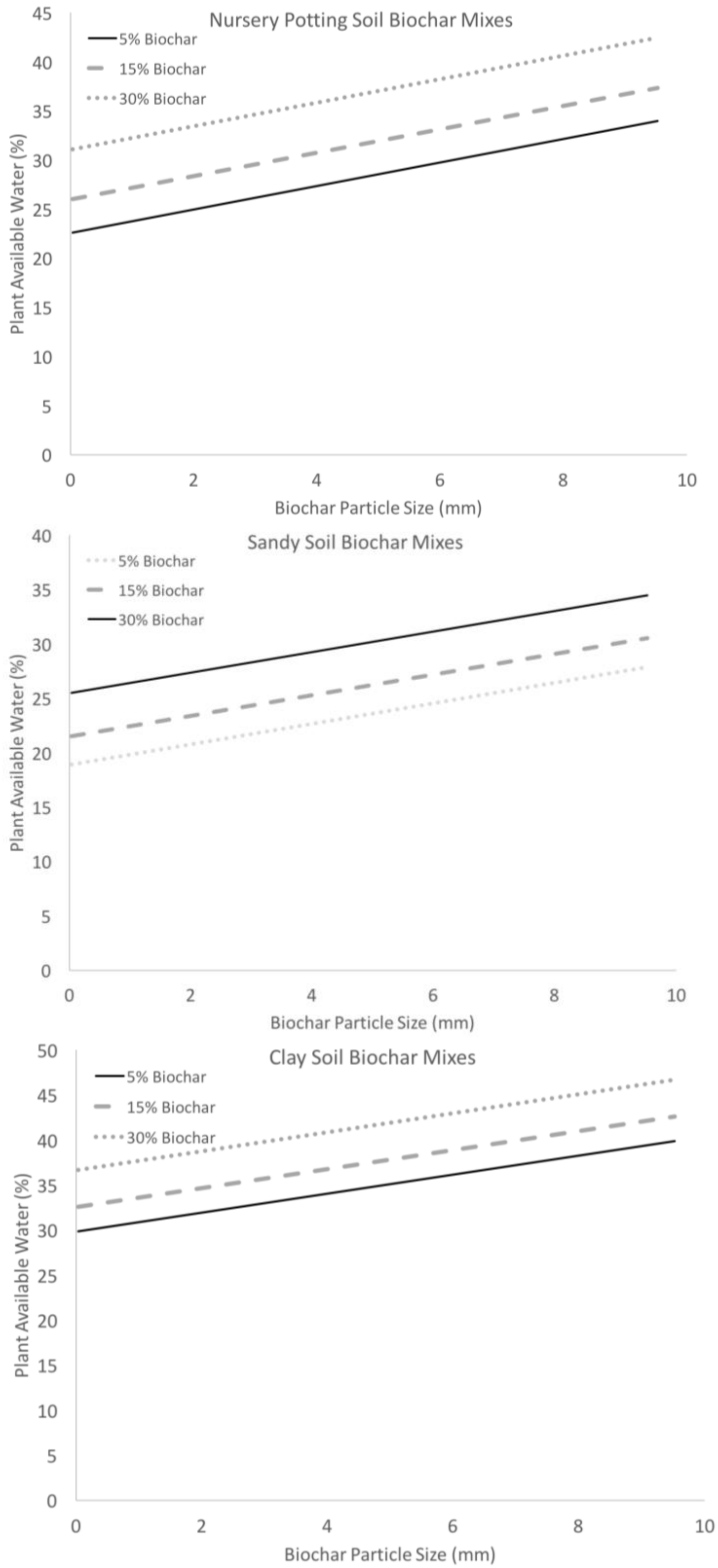


Figure 7 – Shown in the figure are the expected plant available water values for mixes of biochar and a nursery potting mix (top), a sandy soil (middle), and a clayey soil (bottom) when adding different amounts and particle sizes of biochar.

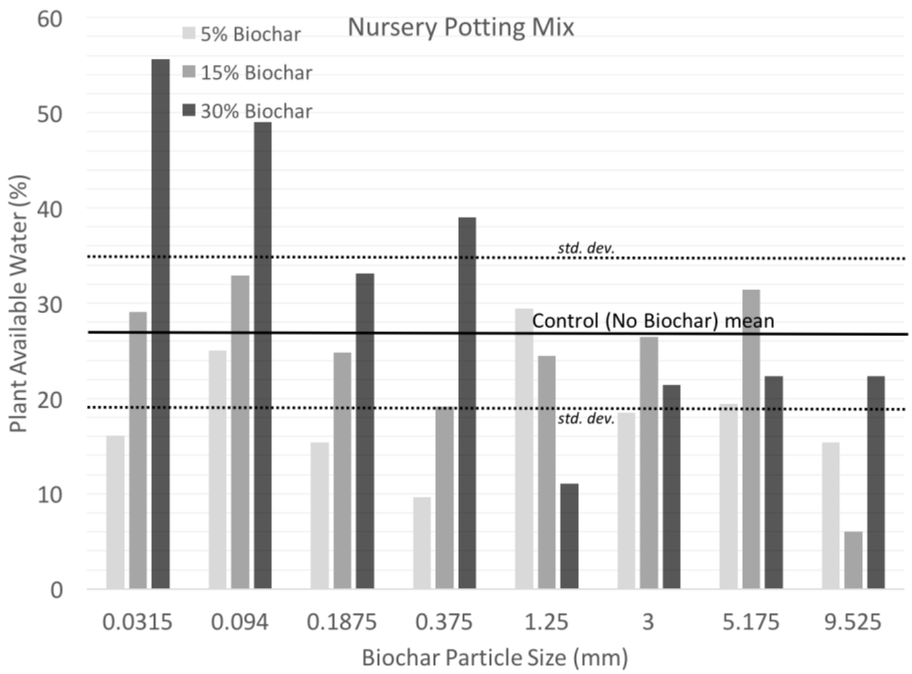


Figure 8 – The plant available water of different amounts and biochar particle sizes when amended to a nursery potting mix. The mean and standard deviation of the media without biochar are indicated by solid and dashed lines respectively for comparison

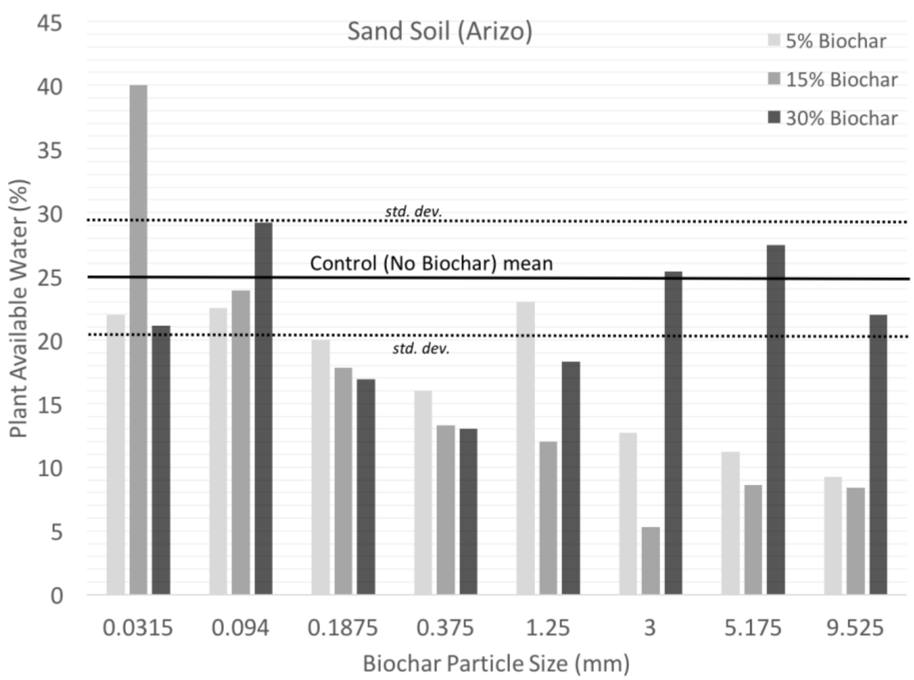


Figure 9 – The plant available water of different amounts and biochar particle sizes when amended to a sandy soil (Arizo series) found in Southern NV. The mean and standard deviation of the media without biochar are indicated by solid and dashed lines respectively for comparison

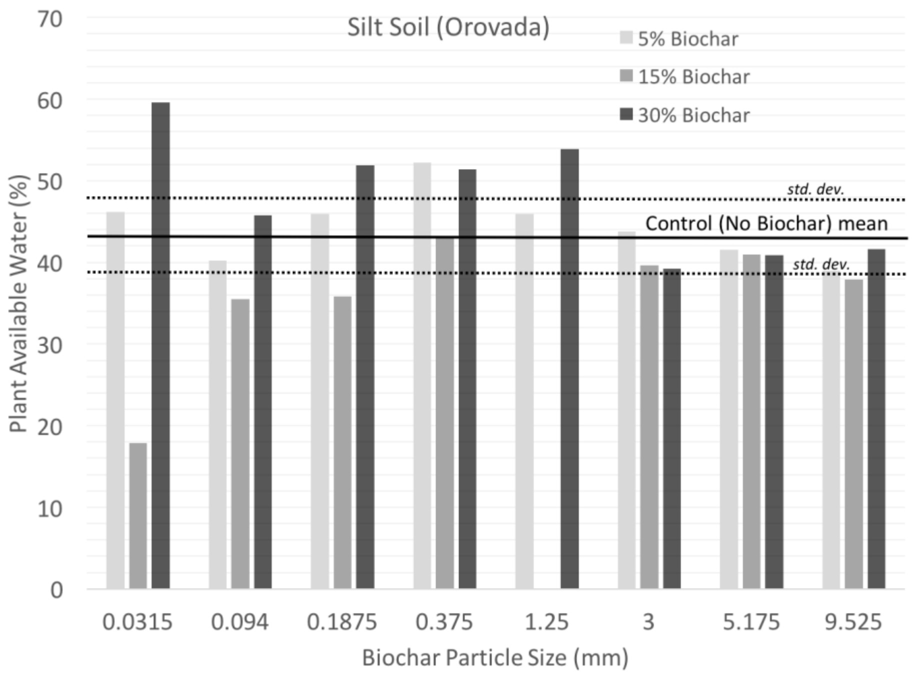


Figure 10 – The plant available water of different amounts and biochar particle sizes when amended to a silty soil (Orovada) found in an agriculturally important region in NV. The mean and standard deviation of the media without biochar are indicated by solid and dashed lines respectively for comparison.

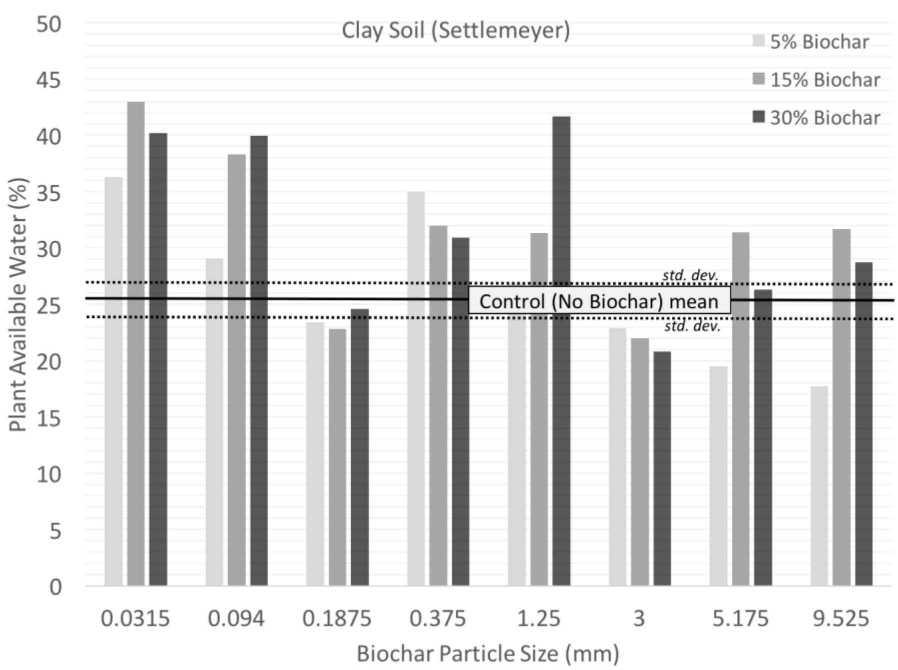


Figure 11 – The plant available water of different amounts and biochar particle sizes when amended to a clay soil found along the Truckee river and in Reno (Settlemeyer series). The mean and standard deviation of the media without biochar are indicated by solid and dashed lines respectively for comparison

Summary and Conclusions

When applying biochar solely for the purpose of improving plant available water, biochar must be tailored to the soil type. When amending a nursery potting mix, the only tangible benefit occurs when biochar is applied at 30% by mass and at particle sizes below approximately 1 mm. Similarly in sandy soils, biochar should be applied at approximately 30%, and with fine particle sized biochar as other applications can decrease plant available water. In a silty soil, there were marginal benefits when applied at 15%, although as with the other soils the most significant improvement occurred at 30% application. Biochar should be processed down to a particle size of 3 mm. or less when amended to silt soils. The most consistent increase in plant available water occurred when amended to a clayey soil found in Reno. Adding biochar to a clayey soil increased plant available water even when amended at a 5% level, although this increase is strongest when the biochar is processed below 3 mm.

The amount and particle size that is added to a given soil will affect the production methodology and the economics of biochar application. For instance, given that biochar generally needs to be amended at approximately 30%, in most soils a larger amount will be generated. To enhance plant available water, the biochar produced in the Nevada Division of Forestry kilns will have to be processed down to a small particle size. The kiln works only with whole wood pieces, as opposed to other biochar production methods that utilize wood chips. During this project several methods were utilized to process the biochar including a woodchipper, a hand-held cement roller, a cement mixer with mixing balls, as well as a mulch chipper that uses a weedwacker type cord. Each of these methods were too laborious and it is likely that a custom piece of equipment should be utilized to process the biochar. Lastly, there are environmental and health implications to processing biochar to a small particle size that should be considered.

Biochar in Urban and Suburban Landscapes

Whether growing trees in tree wells, parks, or private yards, biochar has the potential to increase the survivability of trees. To evaluate the influence of biochar, a greenhouse project was completed by growing trees in the NDF Washoe Nursery greenhouse over two years. Based on consultation with NDF Washoe Nursery staff, three species of tree were chosen for the greenhouse project; Lemmon's Willow (*Salix lemmonii Bebb*), Black Locust (*Robinia pseudoacacia L.*), and Chinese/Lacebark Elm (*Ulmus parvifolia Jacq.*). The willow was chosen because it is a plant with high soil moisture requirements and will be representative of the potential to use trees planted in riparian areas, wetlands, urban rain gardens or other stormwater detention systems (Appendix 3). The latter two are common urban street trees. The three trees were propagated with three different methods, namely from cuttings, seeds with hard coat softening, and directly sown seeds for the Willow, Locust, and Elm respectively. The only species without complete survival was the Willow, which was started from cuttings. The trees were grown using a completely randomized block design, but because the Willow had mortality in some blocks the block analysis was impossible. This reduces the ability to discern differences in Willow properties. More information on the greenhouse tree methods are described in Appendix 1. Trees were grown in the same biochar quantities, although they were grown in only 5 different particle size ranges, as opposed to the 8 particle sizes ranges evaluated in the laboratory.

One of the goals of this project is for private growers to develop the biochar market. Another goal is to assess methods for preparing and processing biochar, including composting. Therefore, the influence of fresh and composted biochar soil mixes produced commercially by Great Basin Organics were evaluated. A pyrolysis unit was built by Great Basin Organics through a loan backed by the US Dept. of Agricultural Rural development. We evaluated the biochar produced by the company to determine the benefit of their unique brand of biochar. Additionally, Great Basin Organics produces composted soil mixes with and without biochar and we evaluated a composted soil (control), a composted biochar soil, and a composted soil with fresh biochar in order to discern the unique influence of the composting process. The components of the 5 soil mixes are outlined in Appendix 1.

Greenhouse Tree Water Availability and Utilization

The influence of biochar on soil water content and actual tree water utilization (transpiration) were evaluated on the trees grown in a greenhouse over two years. The soil water and plant water usage (transpiration) were evaluated using two methods in order to gain knowledge and guide recommendations on biochar utilization in a greenhouse and outside. Firstly, the soil moisture content was measured both after drainage by gravity (field capacity), and 24 hours later between irrigations. Secondly, plant transpiration was directly measured using a device (Licor 6400) which attaches to the leaf and directly measures water leaving the leaf surface (evapotranspiration), as well as carbon dioxide (CO_2) consumption, the latter of which will be discussed in subsequent sections on plant health. This will allow for an analysis of the total water available to plants, and the actual plant water utilization in an irrigated greenhouse to guide recommendations.

Influence of biochar on greenhouse soil water content

As previously stated, the soil water content at field capacity and 24 hours later were compared between different biochar particle sizes and amounts using multiple linear regression, and a separate comparison between biochar treatments and an unamended control NDF potting soil (Appendix 1). For both Elm and Locust, total soil moisture content increased the more biochar was added, and somewhat surprisingly the larger biochar particle sizes had higher soil moisture content. For the Willow, only increasing the particle size increased total moisture content, although the small sample size of the Willow may explain this discrepancy. The influence of particle size is in contrast with plant available water measured in the lab, this likely results from the fact that more of the water is available to plants with finer biochar, or that the hydrophobicity of the fine biochar decreases the infiltration and storage of irrigation water. For the lab project, careful measures had to be taken to saturate the cores with fine biochar due to high hydrophobicity. This data is modelled to give biochar practitioners and nursery growers information on the moisture contents to expect from different biochar mixes (Figure 12).

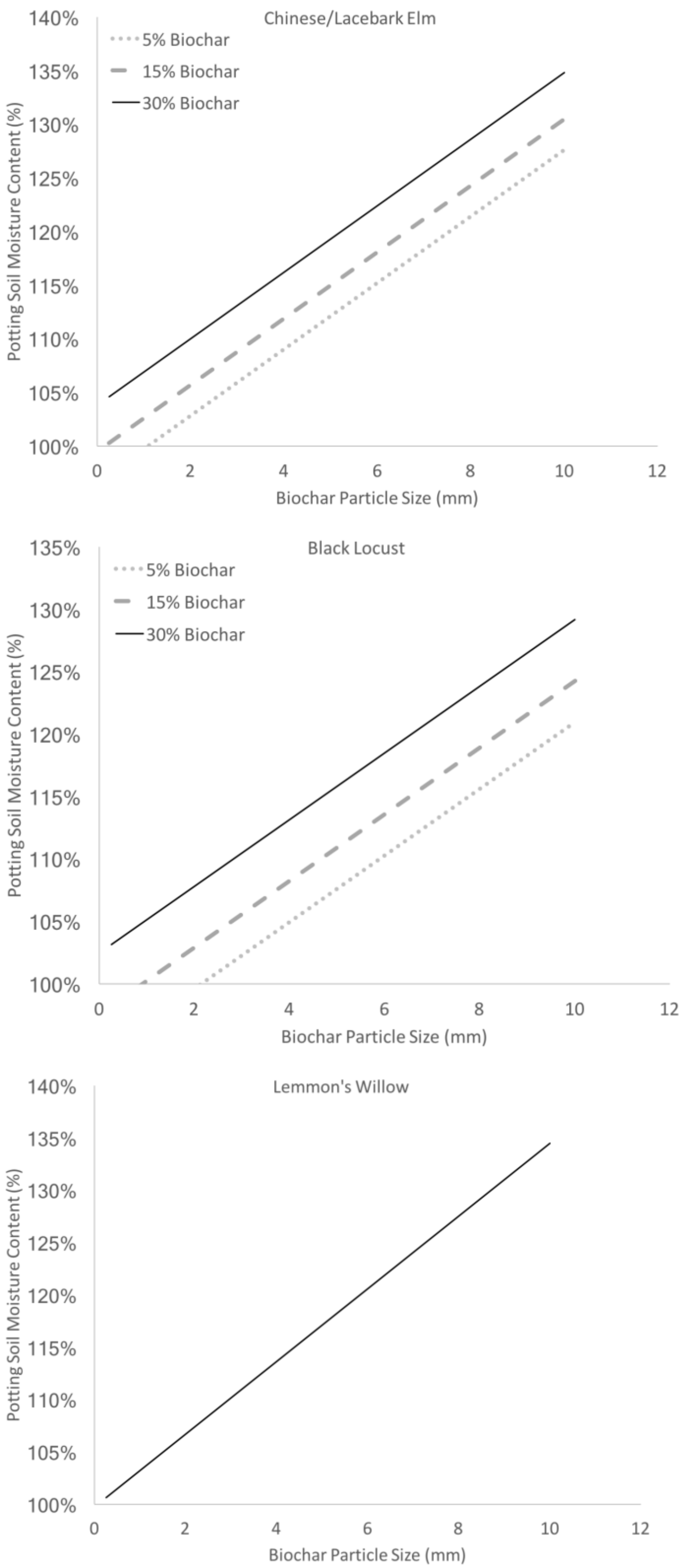


Figure 12 – Shown in the figure are the total soil moisture contents of different amounts and biochar particle sizes of trees grown in a nursery. These results should guide the irrigation in biochar-amended soils in greenhouses.

The total water content generally increased in Elm, Locust, and Willow above the control potting soil for the higher applications (15%, 30%) at particle sizes above 3 mm., while often ultra-fine biochar had a decreased moisture content (Figure 13). As stated previously, this could be due to the increased hydrophobicity of the fine biochar. These results indicate that the total moisture content after irrigation will generally be higher in substantial biochar mixes with larger particle sizes, and that finer particle sizes may present problems when applied.

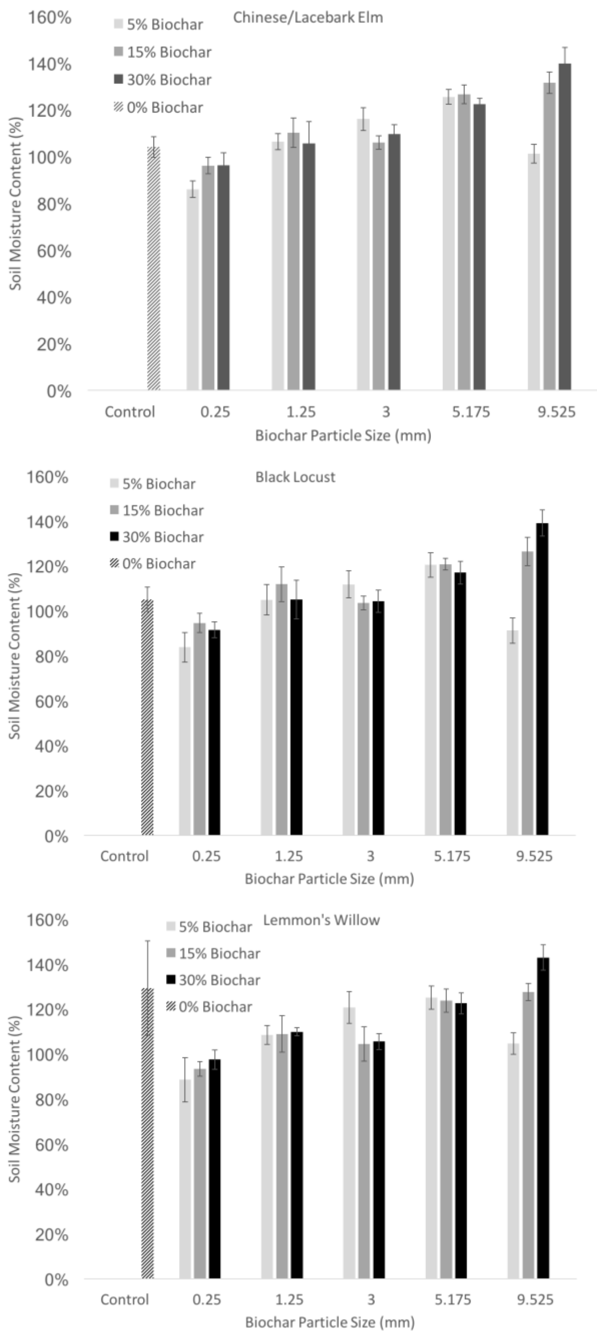


Figure 13 – Shown in the figures are the potential water available for tree transpiration (soil moisture content) of potting soil mixes with different amounts and particle sizes of biochar.

Similarly, within the soil mixes created by Great Basin Organics, the addition of their fresh biochar to a Great Basin organic soil media increased the soil moisture content. The soil moisture content increased by 33% and 34% when fresh biochar was added to the control potting soil in the Elm and Locust respectively. Furthermore, the composting process increased the soil moisture content above composted soil with no biochar, and the same soil with uncomposted biochar. The average soil moisture content increased by 29% and 19% when composted biochar soil mixes were used for the Elm and Locust respectively. These results indicate both that the biochar produced by Great Basin Organics increases total available water, and that biochar composting can increase available water further.

Tree Transpiration

The total soil moisture discussed above indicates the *potential* water available to greenhouse trees in biochar-amended soils after irrigation, although as described previously not all water is available to plants. Therefore, the evapotranspiration rate was directly measured using a Licor 6800 that clips on the leaf and measures water vapor exchange for the Elm and Willow (Locust was excluded). Transpiration rate is a strong measure of plant stress, because healthy plants have open stomata that allows water vapor and CO_2 exchange, while stressed plants close their stomata. Transpiration will be discussed here, and CO_2 will be discussed in subsequent sections. It should be noted that in the greenhouse it is much less likely that a plant will exhibit water stress due to frequent irrigations. To simulate a stress response, watering was withheld for four days shortly before these measurements were taken.

In both trees increasing the amount of biochar increase evapotranspiration rates, although the relationship was highly variable (Figure 14). This high variability indicates that there are other factors contributing to evapotranspiration (e.g. plant genetics, location, differential watering). The results for the comparison to the control potting soil are shown in Figure 15. For the elm trees, the evapotranspiration rate increased from 5% to 15% application rate and plateaued when 30% biochar was added, indicating no significant benefit from increased biochar addition in the greenhouse. The mean evapotranspiration rate of the 5% biochar application for Elm was slightly lower than the control potting soil. For Willow trees the mean evapotranspiration rate was similar to the control, and increased transpiration rates only occurred when 30% biochar was added. Perhaps this is due to the fact that Willow trees require more water, and therefore a higher application rate would provide more soil moisture. The biochar particle size had no relationship to evapotranspiration rates, demonstrating that particle size is not a significant factor on transpiration when growing trees in biochar mixes. There were no significant differences in evapotranspiration rates between any of the soil mixes from Great Basin Organics for either Elm or Willow.

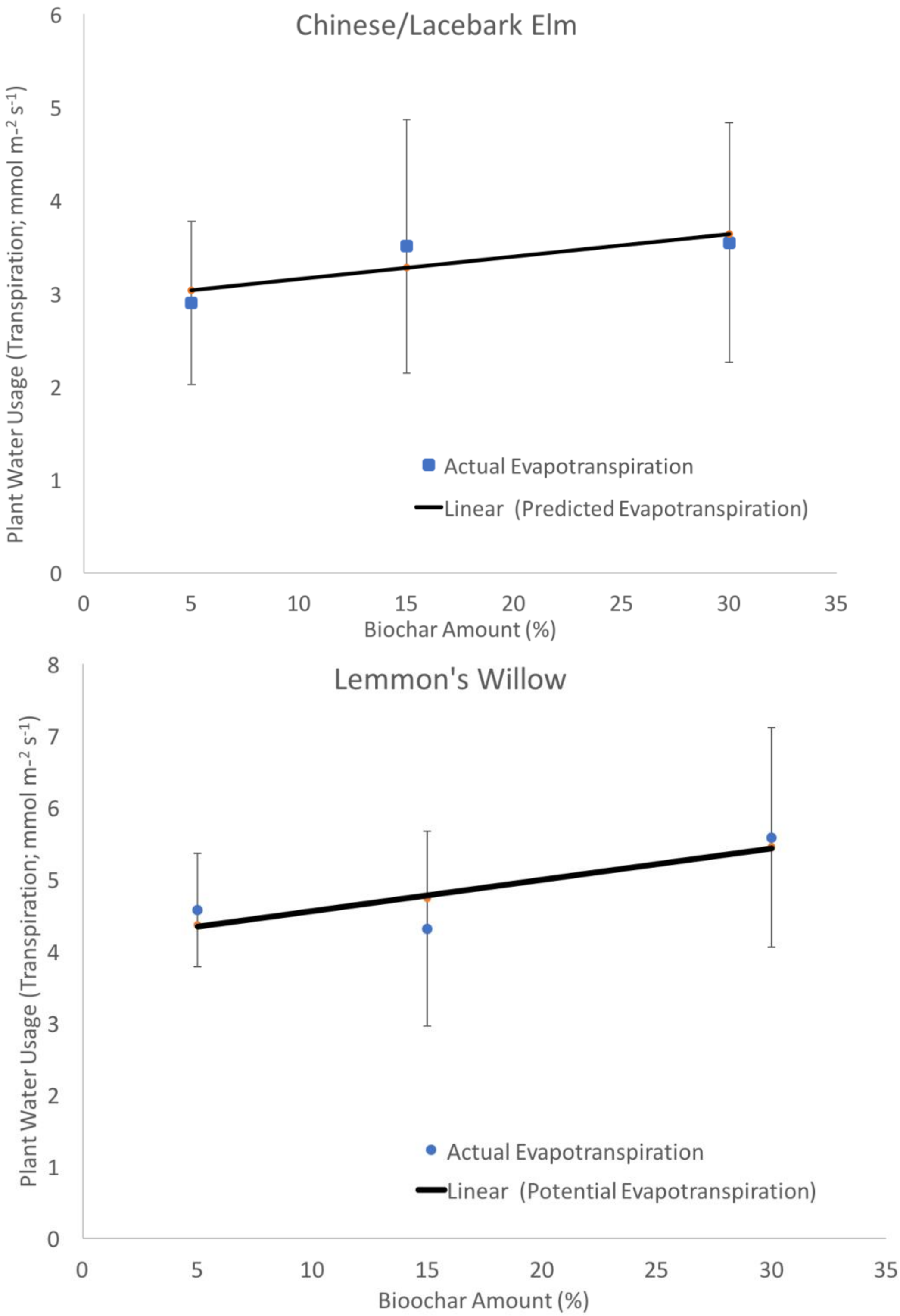


Figure 14 – Shown in the figure are modelled (straight line), and actual (points) Elm (top) and Willow (bottom) evapotranspiration rates of different biochar amounts.

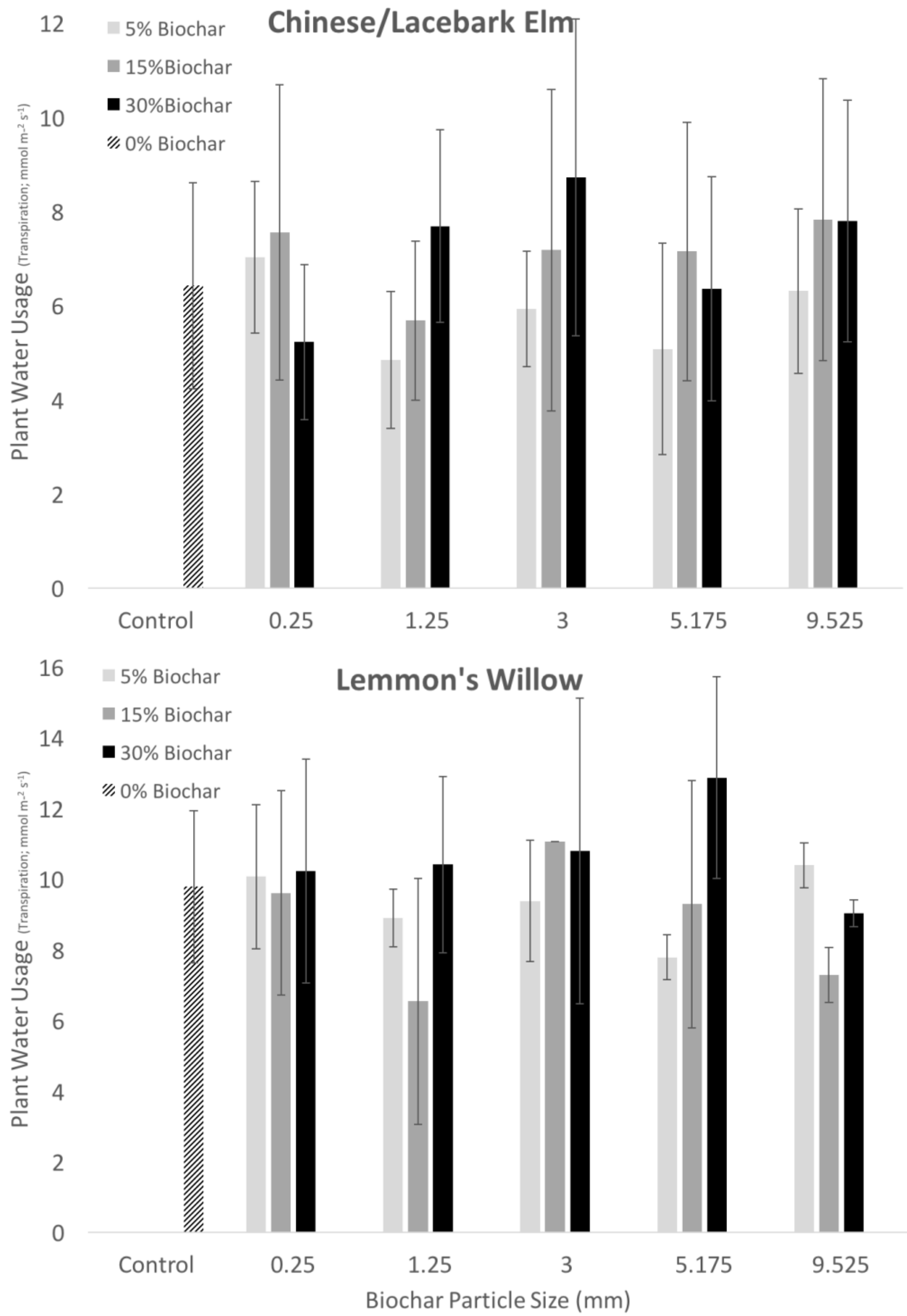


Figure 15 – Shown in the figure are the measured water usage rates (evapotranspiration) of Chinese/Lacebark Elm and Lemmon's Willow in soils with different amounts and particle sizes of biochar.

Plant Health and Photosynthesis

In addition to transpiration, one of the indicators of plant health is the photosynthetic rate. The photosynthetic rate was measured as CO_2 exchange utilizing Licor 6400 leaf sensors. The amount of biochar added to the Elm and Willow trees caused a significant increase in CO_2 exchange at the leaf surface, while as with transpiration there was high variability. Particle size did not influence photosynthetic rate. For the Elm, photosynthesis appears to increase from the 5-15% biochar and levels off, indicating that no further gain is incurred from adding more biochar. For the Willow, increases in photosynthesis are only observed when up to 30% biochar is added. The trends in photosynthesis strongly confirm the results found for transpiration. For Willow, only the 30% biochar application was significantly higher than the control potting soil, with the 5% and 15% application amounts being equivalent (Figure 17). For Elm, there was no significant difference between the control and the biochar treatments.

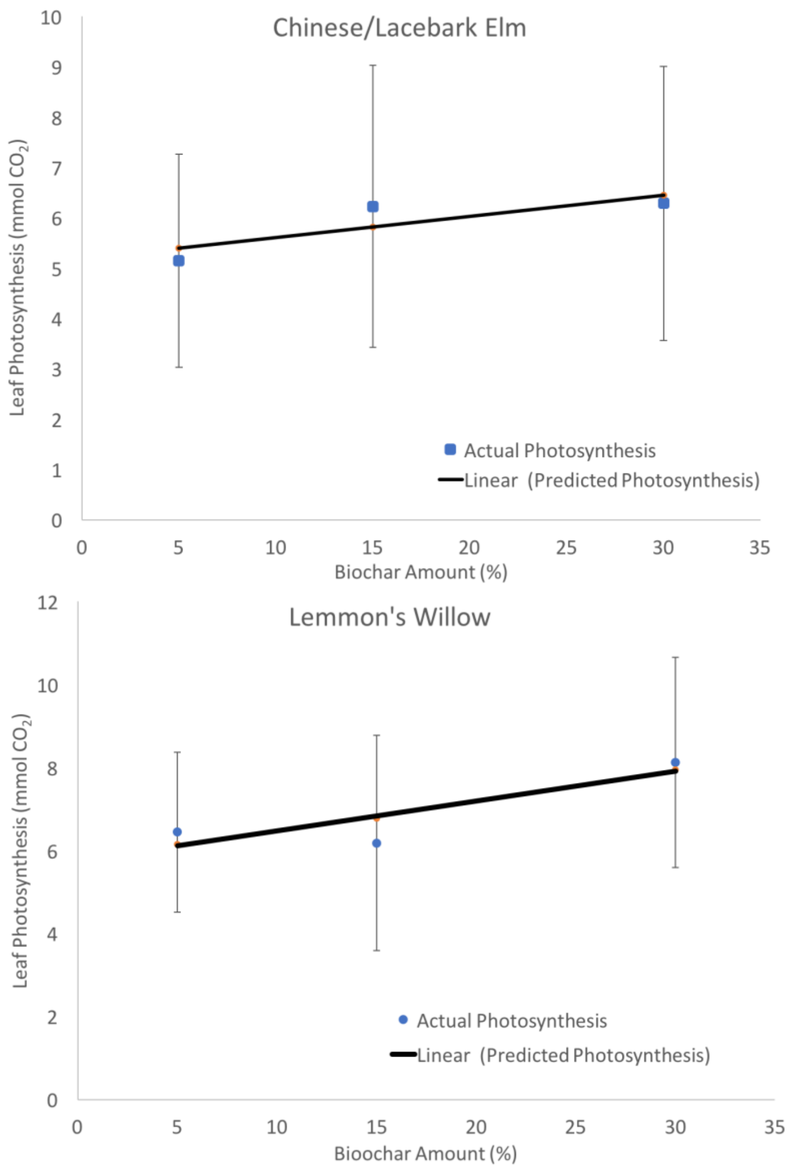
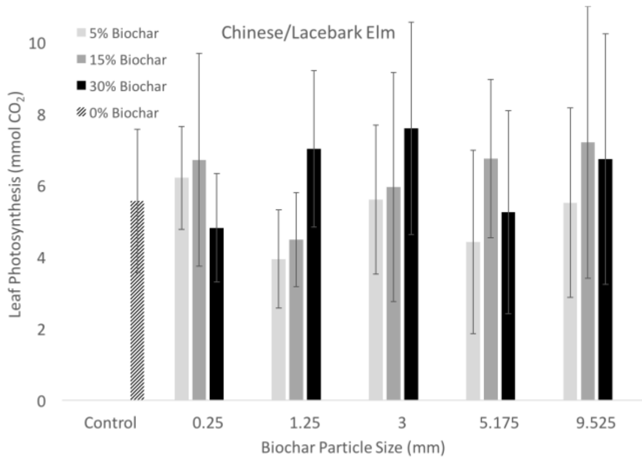


Figure 16 - Shown in the figure are modelled (straight line), and actual (points) Elm photosynthesis of different biochar amounts.



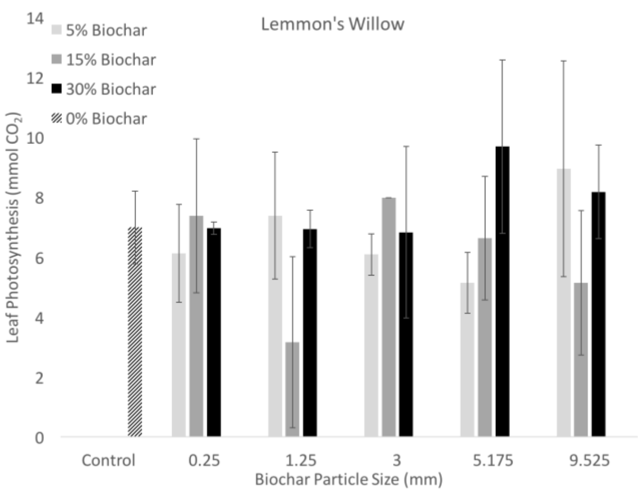


Figure 17 – Leaf photosynthesis for Elm (Top), and Willow (bottom) as a function of biochar particle size and amount.

For Elm, there was an increase in phototynthesis of both composted and uncomposted biochar as compared to the control, although there was no added benefit of the composted biochar (Figure 18). For Willow there were no significant differences found in this small sample size between any of the Great Basin Organics soils.

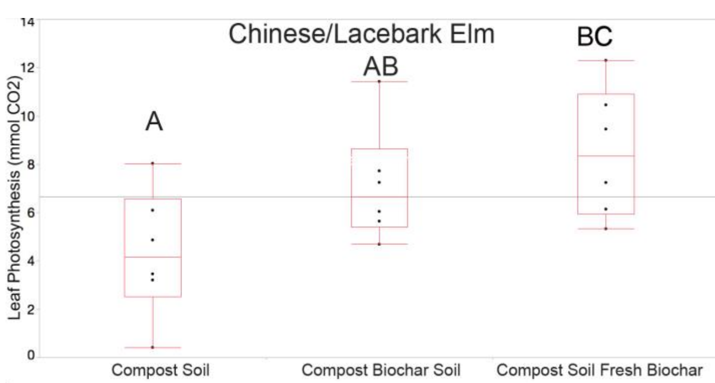


Figure 18 – A comparison of photosynthesis between a Compost Soil (Control), and a Composted Biochar Soil and the same soil with uncomposted (fresh biochar).

Nutrient Retention Evaluation

One of the potential benefits of biochar is an ability to enrich soils with essential plant nutrients. Due to the large reactive surface area of biochar, nutrients can be retained in the rooting zone and enter plant tissue, while in other circumstances nutrients are leached below the root zone. The trees grown in the project were fertilized directly in the irrigation water (Appendix 1). Essential plant nutrients were evaluated in two ways. Firstly, by examining the enrichment of these nutrients in the soils, and secondly by examining nutrients in the trees themselves to determine effective uptake.

Soil nutrient retention

An evaluation of soil nutrients at the beginning and end of a growing season determines the net impact of nutrients that are lost from the soil media from leaching and decomposition of organic matter, and the gain of nutrients from fertilization over the growing season. All biochar treatments retained more nitrogen and phosphorus as compared to the control potting soil, indicating the strong potential for biochar to increase soil fertility (Figure 19). All of the treatments including the control decreased in phosphorus over the growing season indicating net loss, although the loss of phosphorus was much less in the biochar treatments (Figure 19). Most of the biochar treatments gained in nitrogen indicating a net accumulation, while the control soils had a large decline in soil nitrogen.

The increase in plant nutrients was strongest when smaller biochar particle sizes were utilized, and additionally for nitrogen the amount of biochar added significantly increased soil retention (Figure 20). Smaller biochar inherently has a larger surface area for retaining nutrients, therefore it makes sense that there would be a larger nutrient accumulation in the smaller particle size. The retention of nutrients in the soil didn’t appear to be affected by the trees themselves because there was no difference in these nutrient values in containers with or without plants. It should be noted that in prepping the soils, the roots were removed. Together these indicate likely physical and chemical processes in biochar driving the nutrient concentrations. These results indicate the significant benefits in terms of soil fertility in adding biochar, and the benefits from using a smaller biochar particle size.

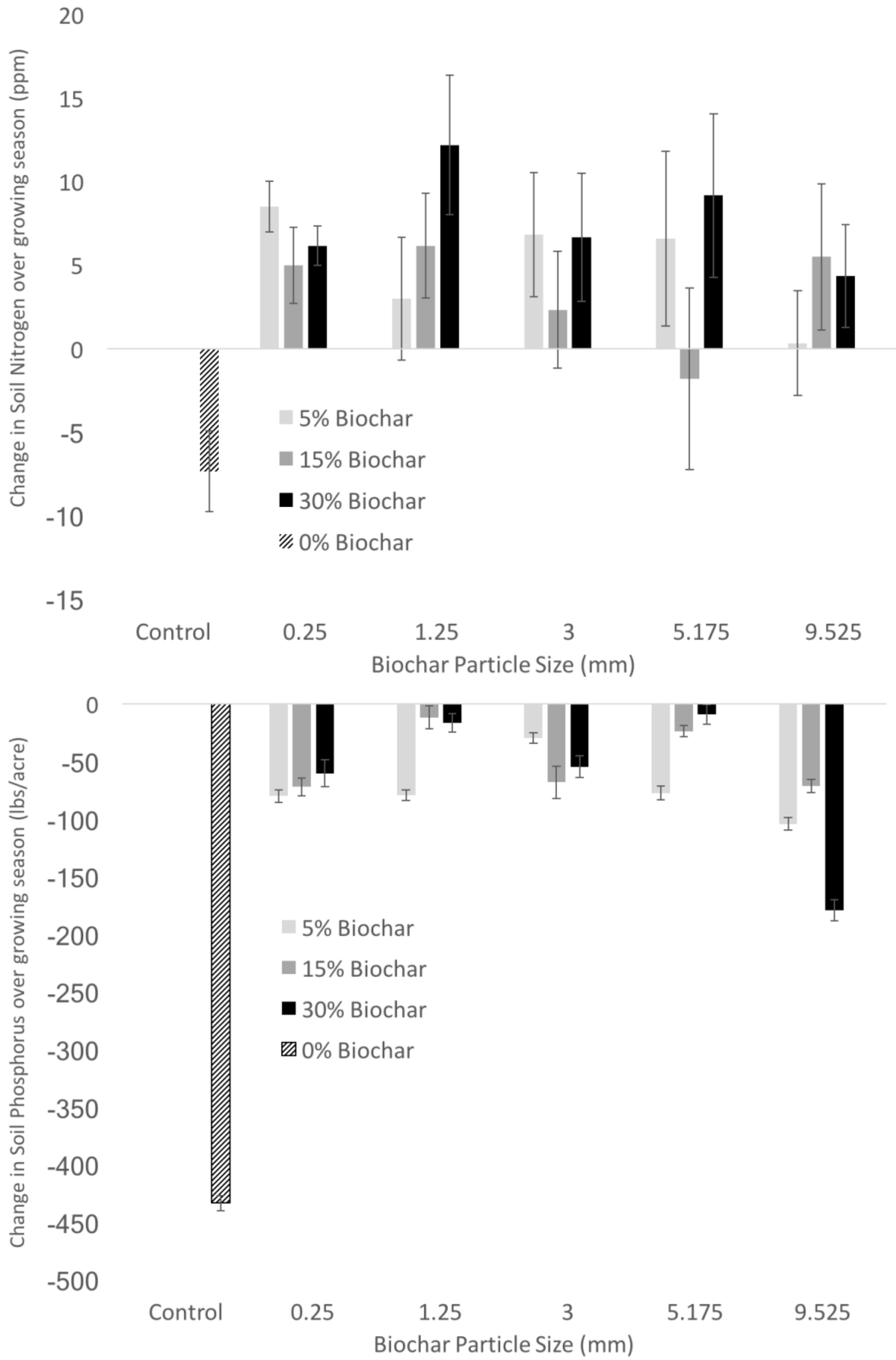


Figure 19 – Differences in soil nitrogen (top) and phosphorus (bottom) values between the beginning and end of the growing season of mixes with different biochar amounts and particle sizes, as well as a control potting soil.

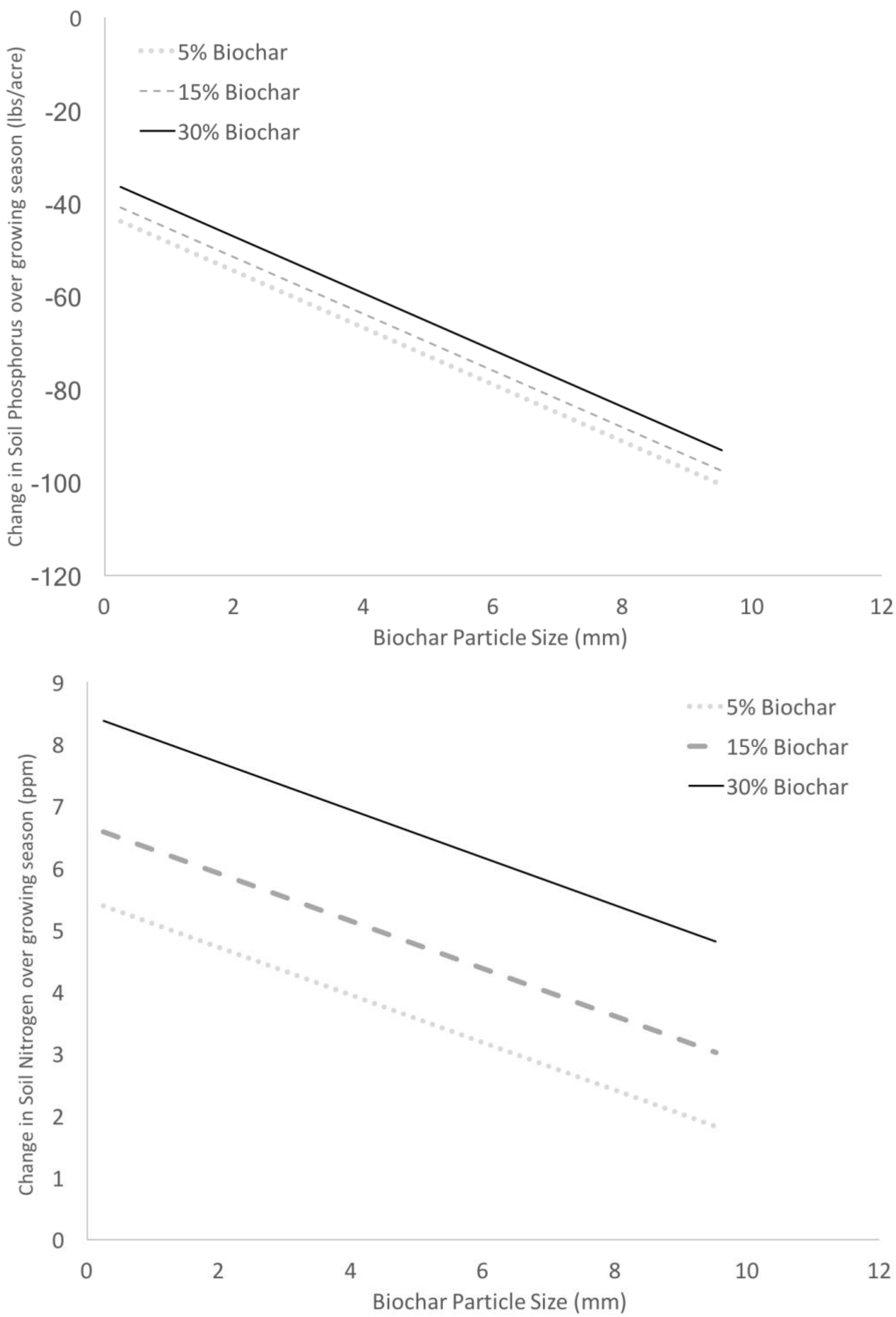


Figure 20 – Modelled differences in soil nitrogen (Top) and phosphorus (bottom) values between the beginning and end of the growing season of mixes with different biochar amounts and particle sizes.

When biochar was composted there was a large and significant gain in both soil nitrogen and phosphorus, while there was generally a net decrease in these nutrients in the composted mix alone and in soils with uncomposted biochar (Figure 21). This indicates a large benefit to composting biochar in terms of soil fertility.

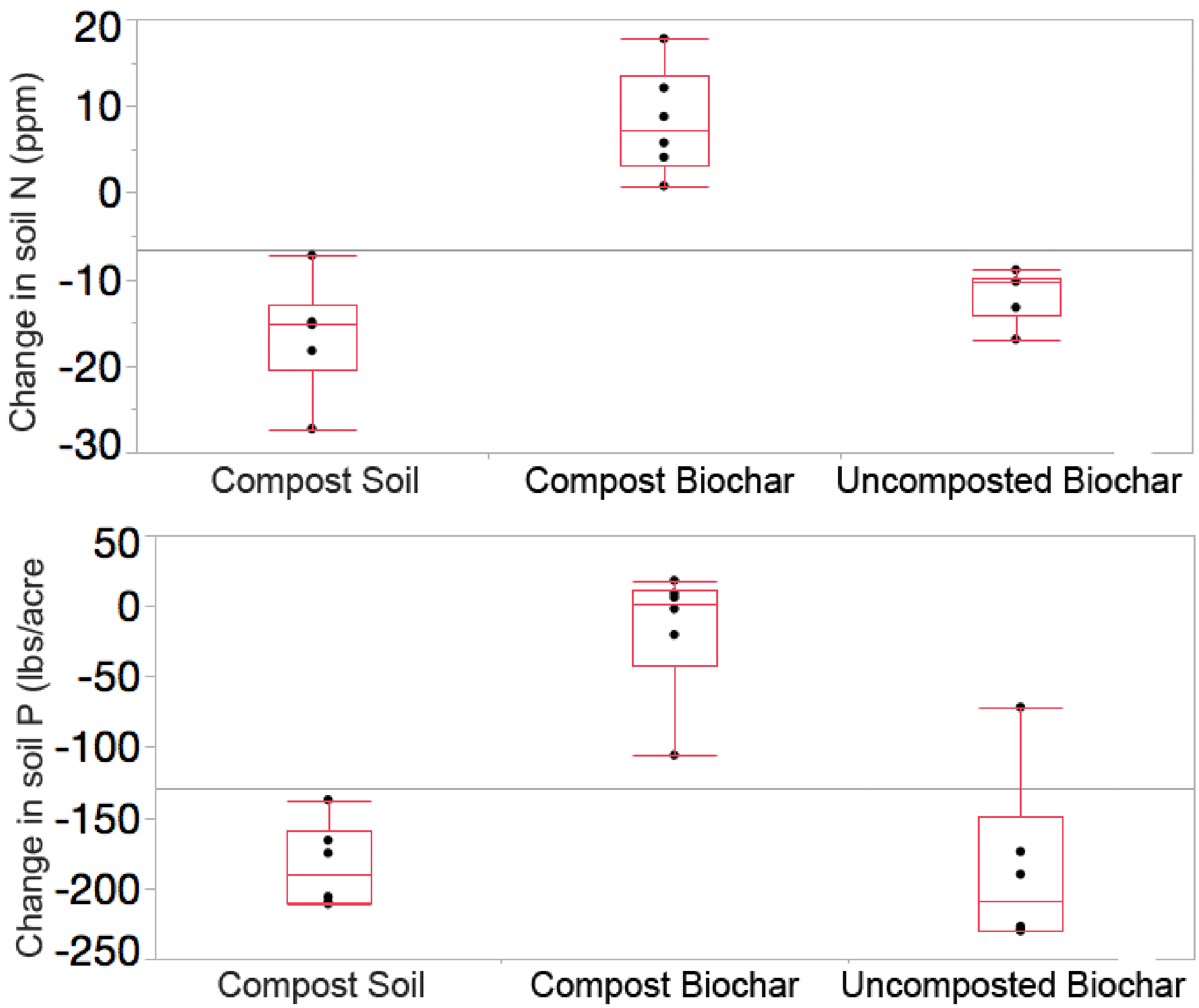


Figure 21 – A comparison of soil nitrogen (top) and phosphorus (bottom) differences between the beginning and end of the growing season between a Compost Soil (Control), a composted biochar soil, and the same soil with uncomposted fresh biochar

Tree nutrient retention

Essential plant nutrients (N, P, Ca, K, Mg, S, B, Mn, Fe, and Zn) were quantified on the tissue of the trees themselves to determine if the biochar influenced plant uptake. This was done for above and belowground tissue separately for the Chinese/Lacebark Elm, and for all tissue combined for the Locust.

Adding more biochar to the potting soil positively increased the amount of aboveground and belowground phosphorus and calcium and additionally the belowground Magnesium. There was no significant relationship with other plant nutrients and biochar particle size played no role. Potassium was negatively related to belowground tissue, possibly indicating the greater ash content of the finer material because ash is enriched in potassium, and it was difficult to remove the ash content from this fine fraction. As compared to the control, belowground Phosphorus, Calcium, and Magnesium were generally greater in the highest biochar application amounts (15-30%), and aboveground phosphorus at larger biochar applications. In most circumstances, there was no difference between 0 and 5% biochar applications indicating a lower bound to biochar application. Interestingly, Manganese was negatively correlated with biochar amount for both above and belowground biomasss.

Aboveground nitrogen was significantly lower in the composted biochar as opposed to the uncomposted biochar. The nitrogen was highest in the belowground Elm grown in composted soil with no biochar, and there was no difference between composted and uncomposted biochar. There were no differences in any other nutrients. These results indicate potential nitrogen limitation in both composted biochar and uncomposted biochar mixes.

Further 'Biochar in Urban & Suburban Landscapes' work

In the relatively short duration of this project it became difficult to transplant trees from the greenhouse to conduct field trials in test plots. Instead, we determined that the most benefit to the project came from focusing on doing a thorough study of the trees in the greenhouse and keeping them alive so that test plots could be done in the future. Some of the trees were destructively sampled, but numerous Willow, Elm, and Locust are kept alive by NDF staff in the greenhouse. Test plots would allow us to determine health and survival under real-world conditions, with environmental stressors including drought, compaction, and other disturbances. It is difficult to make strong pronouncements on biochar utility, and provide guidance in this realm from a short period in the uncontrolled environment outdoors. We couldn't be certain if a tree wasn't doing well because it was eaten by an animal, tripped over by a person, or due to biochar application. The greenhouse provides a controlled, albeit unrealistic, environment for comparison to biochar impacts outdoors.

Further accomplishments

In the duration of this project a unique opportunity to collaborate with the Tahoe Conservation District and the Nevada DOT to use biochar in a rain garden was presented. Rain gardens are urban landscapes that are used most predominantly for stormwater storage and remediation. Resulting from this project, we amended a rain garden near Incline Village, NV as part of efforts at Lake Tahoe watershed management. A fact sheet (Appendix 3) was produced detailing this project.

Education and Outreach

There is a strong interest in biochar amongst the general public, nursery growers, foresters, academics and others. This project presented the opportunity to provide education and outreach in multiple venues including:

- A scientific poster at the Soil Science Society of America Annual Conference in Tampa Florida entitled, *Assessment Of Pinyon and Juniper Derived Biochar As a Soil Amendment To Improve The Survivability Of Urban Trees and Landscapes* (Appendix 2).
- Rain Garden Fact Sheet developed to educate practitioners in Tahoe and beyond on the potential of biochar to be utilized in urban rain gardens and stormwater detention areas (Appendix 3)
- UNR Eureka Field Day – Presentation on this project to interested parties and city council members entitled, '*Pinyon Juniper Plant Nursery and Urban Street Tree Applications*'.
- Presentation in Missoula on the project to the Forest Service Wood and Biomass Coordinator by Eric Roussell.
- An oral presentation at the Soil Science Society of America Annual Conference in Milwaukee entitled, *Nutrient & Water Retention Dynamics of Biochar Produced from Pinyon-Juniper Forest Thinning in Nevada* (Appendix 4).
- Presentation at the NDF 5 year review
- Biochar Shade Tree Professionals. Presentation to this group twice, entitled, *'Evaluating the Utility of Pinyon and Juniper Derived Biochar as a Soil Amendment to Improve Urban Tree Survival'* and '*Assessment of Pinyon & Juniper-derived biochar as a soil amendment to improve survivability of urban trees'***.**
- Green Professionals Presentation entitled, 'Evaluating the Utility of Pinyon and Juniper Derived Biochar as a Soil Amendment to Improve Urban Tree Survival'.
- Presentation at the Fall Tree Care Seminar in Carson City entitled, '*Biochar and Drought in our Parks, Gardens and Stormwater Detention Systems'*.
- I was invited to co-chair an entire poster session on biochar at the American Geophysical Union annual conference in San Francisco.
- Consultations with the commercial biochar practitioner Dink Getty from Genoa Trees and Great Basin Organics.

Conclusions and Recommendations

Biochar has the potential to be a useful soil amendment in the urban environment to reduce drought stress, increase soil fertility, and plant health. From the lab to the greenhouse we produced a careful analysis of these biochar benefits in order to guide both biochar producers, as well as those looking to apply biochar in the landscape. As with many other studies of biochar, the impacts of this soil amendment are highly variable, although some general pronouncements and recommendations can be made from this project. It is important to note that the positive benefits of biochar are variable, although there were few negative implications from using biochar. By using multiple linear regression we were able to produce models of plant available water, plant health, and more that can be used as specific guidelines when PJ biochar is used.

Despite the limited control of feedstock and temperature, the biochar produced by the transportable metal kiln has favorable properties compared to biochar produced under controlled conditions. In that sense, the kiln is an effective way to produce biochar. There are limitations to the kiln. In this project, we did not take in to account the efficiency of the kiln in terms of the wood inputs and biochar outputs, instead focusing on the soil and plant-growth stimulating properties of biochar. The fact that this is a batch, rather than flow-through process that takes 48 hours, and doesn't produce any marketable by-products will reduce the efficiency of this approach compared to other biochar production methods. Another limitation centers around the smoke produced. A casual observation of the kiln indicates that the smoke produced will not make a significant visual impact or become a direct nuisance, especially considering that the biochar is produced at locations where burn permits are approved for wood that is slated for pile-burning. We were unable to do an analysis of the content of the smoke in this project. Beyond these limitations, the kiln has significant benefits to wildland foresters already mentioned including transportability, safety, durability, and ease of use.

One of the goals of this project has been to transfer information to the commercial sphere, and it is exciting to see Great Basin Organics produce a commercial biochar product. The air quality impact becomes important when commercial producers are involved. State and Federal foresters have staff to acquire burn permits, and these burns generally take place in remote locations where the smoke will not be a nuisance. Great Basin Organics has had difficulty continuing their operations due to an expired permit, and due to the fact that they are located in a valley with an inversion layer in a relatively well-populated location. This will be an ongoing problem with other commercial producers as well. Great Basin organics was granted a temporary permit to produce biochar, and once that permit expired the didn't have the resources to provide results of the air quality impacts of their biochar production method. Assistance to commercial biochar producers to determine the air quality impact will be essential if biochar is to commercialize.

One of the potential benefits of biochar is the longevity of this organic carbon, as opposed to other organic soil amendments. Therefore, when it is applied to soil it will continue to benefit for a long duration, and also there is a potential for carbon sequestration when biochar is produced. In this project, we did not evaluate the longevity of the biochar. We did measure the amount of biochar produced, and the amount of carbon in the biochar, but we did not confirm the longevity of the material. Additionally, a full assessment of carbon sequestration would require a determination of the heat-trapping gasses released during biochar production and a comparison to those gasses released during standard combustion and other status-quo measures of fuels reduction.

Producing PJ biochar at higher temperatures ~700°C, creates a material with a high surface area and a higher concentration of nutrients. It is very clear that adding biochar to soils significantly increases the soil fertility. This occurs not because the biochar is a fertilizer in itself, but because the high surface area of biochar likely retains more nutrients added from fertilizer, rainfall or other sources. The inherently higher surface area of smaller biochar particle sizes caused soil fertility to increase because added fertilizers were retained by this biochar type. If increasing soil fertility is the goal of biochar application it is important to use finer biochar particle sizes. Additionally, plants grown in biochar mixes had increases in some essential plant macronutrients in their tissues (Phosphorus, Calcium, Magnesium).

One of the other potential benefits measured in this project, is the potential of biochar to ameliorate drought stress, and underwatering that can occur with trees in arid environments. If managing soils for drought stress, it is essential to add biochar in large quantities (~30%) regardless of the soil type used. The particle size had a strong influence on plant available water, therefore if the goal of biochar application is to increase available water then finer biochar is more appropriate. Contrastingly, the ultra-fine biochar was strongly hydrophobic and unless there is a drenching rain/irrigation these soils may not become saturated. The strongest benefit for increases in plant available water occurred in the potting soil and the clay soil; there was limited benefit when biochar was mixed with sandy and silty soils. Adding small amounts of biochar can actually decrease plant available water in sandy soils, therefore higher biochar amounts should be added in these soils.

Ultimately, measurements of plant health get to the crux of the influence of biochar as a soil amendment. Plant health as measured by evapotranspiration and photosynthesis increased the more biochar that was added, and particle size of biochar had no influence on these metrics. The fact that biochar particle size doesn't play a role in these plant health indicators is very important. The biochar produced by the NDF kiln produces a heterogenous mixture of material, if the material doesn't need to be sieved and sorted it will save a lot of time and money. The increase in these plant health metrics was highly variable indicating that biochar explains only a portion of plant response. It was clear that there was a slight decrease in plant health when small (5%) amounts of biochar were added. In trees with high water demands (e.g. Willow), biochar needs to be added in higher amounts (~30%), while in most trees adding more than 15% produces no added value.

Through this project, we evaluated the potential benefits of composting biochar by assessing a composted biochar product produced by Great Basin Organics. The composting process increased the soil moisture content and provided significant benefits in terms of soil fertility. Photosynthesis did increase when biochar was added, although the composting process added no further value.

Overcoming the limitations discussed here, and closing knowledge gaps will continue to further the use of biochar in the landscape. Test plots can present results on real-world applications of biochar, and evaluations of the air quality impacts will facilitate the development of biochar in the commercial sphere. It is clear that at least in nursery operations, biochar provides a significant benefit as a soil amendment. The extent of biochar adoption will depend on the production cost as compared to the marketable value. In this project, we demonstrated and quantified the benefits of biochar to justify the market value, and guide the use of biochar in the landscape.

Appendix 1: Details and Methods of the Project

Biochar Production & Carbon Sequestration

Kiln Methodology

Biochar was produced using a transportable metal kiln (**NDF Biochar**) and under temperature-controlled conditions in a USDA-ARS laboratory in New Orleans. The transportable metal kiln consists of two separate circular metal sections that taper to a dome at the top. The bottom section sits on top of four inlet pipes and four outlet chimneys that extend above the top of the kiln. The kiln is 234 cm. in circumference and 178 cm. in height to the bottom of the cone with a volume of approximately 7.65 m^3. Biochar was produced in the transportable kiln by; loading the kiln with mixtures of Pinyon pine (*Pinus monophylla*) and Juniper (*Juniperus osteosperma*), lighting a fire underneath the kiln, adding chimneys and closing off atmospheric contact with sand/mud after one hour, allowing pyrolysis to occur for 24 hours, and extinguishing the fire and allowing it to cool for another 24 hours.

Controlled Temperature Biochar Methodology

Pure samples of Juniper or Pinyon were located in a ceramic evaporating dish (350°C) or a stainless steel basket (500°C and 700°C) and placed in to a Lindberg bench furnace equipped with a retort (Lindberg/Blue M, Waterton, WI). The pyrolysis temperature was gradually increased from room temperature to the target temp at 10°C/min until the desired temperature was reached. Wood was pyrolyzed at 350°C, 500°C or 700°C with a one-hour holding time under a flow of nitrogen gas with a flow rate of 1.6 L/min. Biochar was cooled at room temperature for 12 hours in the retort under the same N_2 flow regime. All biochar types were mechanically ground and sieved to pass through a 2 mm. sieve.

Kiln Temperature

The temperature of the kiln was measured at three different locations (bottom, middle, top) over a period of four different biochar production periods. The temperature was measured with a k-type thermocouple by drilling in to the side of the kiln and inserting the probes for the duration of the burn.

Carbon and Biochar Mass Estimates

It is difficult to estimate the amount of wood, and the resulting amount of biochar that is produced in such a large kiln, with a homogeneous mixture of wood and biochar with any accuracy. Therefore, we utilized two different methods to come up with independent estimates. The two methods are named 'Wood Cut Method' and 'Wood Weight Method'. The resulting values for the methods were in good agreement, indicating that the estimate is sound.

Wood Cut Method

The biochar was loaded in to the kiln as it usually is. During loading, three subsamples of the wood were collected and averages. Subsamples were collected by using a chainsaw to cut out known volumes of wood, the resulting wood was weighed, a 'wood density' was calculated, and extrapolated out to the whole kiln based on the kiln volume and height of loading.

Wood Weight Method

Using this method, every piece of wood that was loaded in to the bottom half of the kiln was weighed before being loaded in to the kiln, and packed as normal. The estimate was doubled to account for the whole kiln.

Biochar Mass Estimate

Biochar mass was estimated by using a soil core of known volume to take a biochar core from the top of the pile to the bottom. Each core was weighed to determine the 'biochar density'. This was done at five separate locations and the results were averaged. Because the biochar pile did not encompass the whole kiln, the height of biochar was measured with a probe at 7 different locations and the results were extrapolated.

Carbon Analysis

Total carbon was quantified on a thermal conductivity detector after dynamic flash combustion (LECO TruSpec Carbon Analyzers, St. Joseph, MI) by Oklahoma State University on 14 subamples we collected. Total carbon contents of the wood were taken from 'Pinyon Pine and Juniper Biochar Application to Four Eastern Nevada Soils, Jim Ippolito, A report to the USDA-ARS Northwest Irrigation and Soils Research Laboratory.

Biochar Properties

Surface Area

Surface area measurements were obtained from nitrogen adsorption isotherms at 77 °K using a Nova 2000 Surface Area Analyzer (Quantachrome Corp., Boynton Beach, FL, USA). Specific surface areas (BET, Brunner-Emmett-Teller) were taken from adsorption isotherms using the BET equation.

Biochar Chemical Analyses

Total carbon and nitrogen were quantified on a thermal conductivity detector after dynamic flash combustion (LECO TruSpec Carbon and Nitrogen Analyzers, St. Joseph, MI) on triplicate samples. The pH was analyzed on triplicate samples with a pH probe on a 1:2.5 mixture. Bioavailable and exchangeable plant macronutrients (Ca, Mg, P, K) were extracted on duplicate samples using a Mehlich 3 extraction and quantified on an inductively coupled argon plasma spectrometer.

Biochar as a Soil Amendment

Plant Available Water in Nevada Soils with biochar

Orovada, Settlemeyer, and Arizo soil locations were determined with soils maps and ground-truthed to confirm. Soils were collected with a soil core in the top 5 cm, sieved to remove particle sizes greater than ¼", and oven dried at 105°C for 72 hours. The NDF potting mix was supplied by Washoe Nursery staff. The components for the soil mix consists of: 3 parts vermiculite, 3 parts perlite, 1 part dissolved granite, and three parts of a proprietary Readi-Gro soil mix that consists of composted fir bark and other ingredients.

Biochar was sieved to produce the measured particle sizes for all the studies. When necessary, biochar was ground with a mortar and pestle to produce finer particle sizes. Biochar was mixed with soils by weighing each portion in to a container, shaking the container in a random fashion, opening the container and stirring, then collecting portions of the mix with a cup. The mix was collected in the cup by sampling from the top to bottom to ensure there was limited particle size sorting. The cups were scooped and loaded in to the core in at least 5 different increments, and after each increment they were packed equivalently by dropping a weight from a known height at three different locations. Soil cores were saturated and analyzed using Decagon Hyprop manufacturer recommendations.

Biochar in Urban and Suburban Landscapes

Greenhouse methods

Biochar soil mixes were produced in batches by weighing each fraction in to a small container, shaking the container in a random fashion, and adding it to a larger container in increments. The soil mixes were loaded in to nursery containers by nursery staff using standard methods, and all seeds and cuttings were propagated by the nursery manager using standard methods. Subsamples were collected, dried at 105°C for 72 hours, and analyzed using methods described in this document. For the first growing season, the soil mix described above was utilized. After the first growing season, nursery staff carefully transferred each plant in to larger containers filled with a 'Transplanting/bareroot mix' that consists of 8 parts Readi-Gro, 1 part peat moss, 1 part vermiculite, 1 part perlite, and 1 part Rice Hulls. The soil description for the Great Basin Organic soils are described in the table below. The soils were supplied by the company owner, and they were adapted in to a lighter potting mix in consultation with NDF staff by replacing the Readi-Gro portion of the NDF soil mix with the Great Basin Organic soil. Composted soils are produced on mixes of 36 parts woodchips, 18 parts manure, 9 parts coffee bean waste, and 7 parts biochar for the composted biochar mix. Material was composted in standard rows and turned.

Genoa Trees Soil Mix	Genoa Trees Soil Mix with Fresh Biochar	Composted Soil Mix	Composted Soil-Biochar Mix	Composted Soil w/ Fresh biochar
8 part Genoa Trees Soil mix	8 Part Genoa Trees Soil Mix	8 Part Composted Soil Mix	8 Parts Composted Soil & Composted Biochar Mix	8 Parts Composted Soil & Fresh Biochar Mix
1 part peat	1 Part Peat	1 part peat	1 part peat	1 part peat
1 part vermiculte	1 part vermiculite	1 part vermiculite	1 part vermiculite	1 part vermiculite
1 part perlite	1 part perlite	1 part perlite	1 part perlite	1 part perlite
	4.8 part fresh biochar			

Each biochar treatment was grown in six blocks with six replicated in a completely randomized block design. Plants were fertigated with overhead irrigation from every 1 to 3 days depending on climate and growing season. The irrigation water is pumped from a well an amended with essential plant nutrients. The final concentrations in the irrigation water in ppmare shown below.

Targets	Nitrogen	Phosphorous	Potassium	Calcium	Magnesium	Iron	Boron	Sulfate	Zinc	Manganese
High N	150	50	50	90	30.0	2	0.5	250	0.05	0.5
Low N	50	50	70	70	25.0	2	0.5	250	0.05	0.5

Influence of Biochar on greenhouse soil water content

The soil moisture content was determined at field capacity and after 24 hours. Field capacity was determined as the period where there was no water visibily dripping from the containers (usually 3 hours after watering). Each container was weighed at the appropriate time. The weights measured were compared to container dry weight measurements to determine soil moisture content.

Tree Transpiration

Transpiration was measured with the Licor 6400 by clipping the leaf and following manufacturer instructions. Measurements were taken 24 hours after irrigation. Transpiration was measured as the difference in water content between a reference, and the sample cell attached to the leaf.

Plant Health and Photosynthesis

Photosynthesis was measured with the Licor 6400 by clipping to the leaf and following manufacturer instructions. Photosynthesis was measured as the difference in CO_2 between a reference and sample cell attached to the leaf.

Soil Nutrient Retention

Soils were collected from each Locust container, homogenized and analyzed by the Oklahoma State University lab following protocol described above.

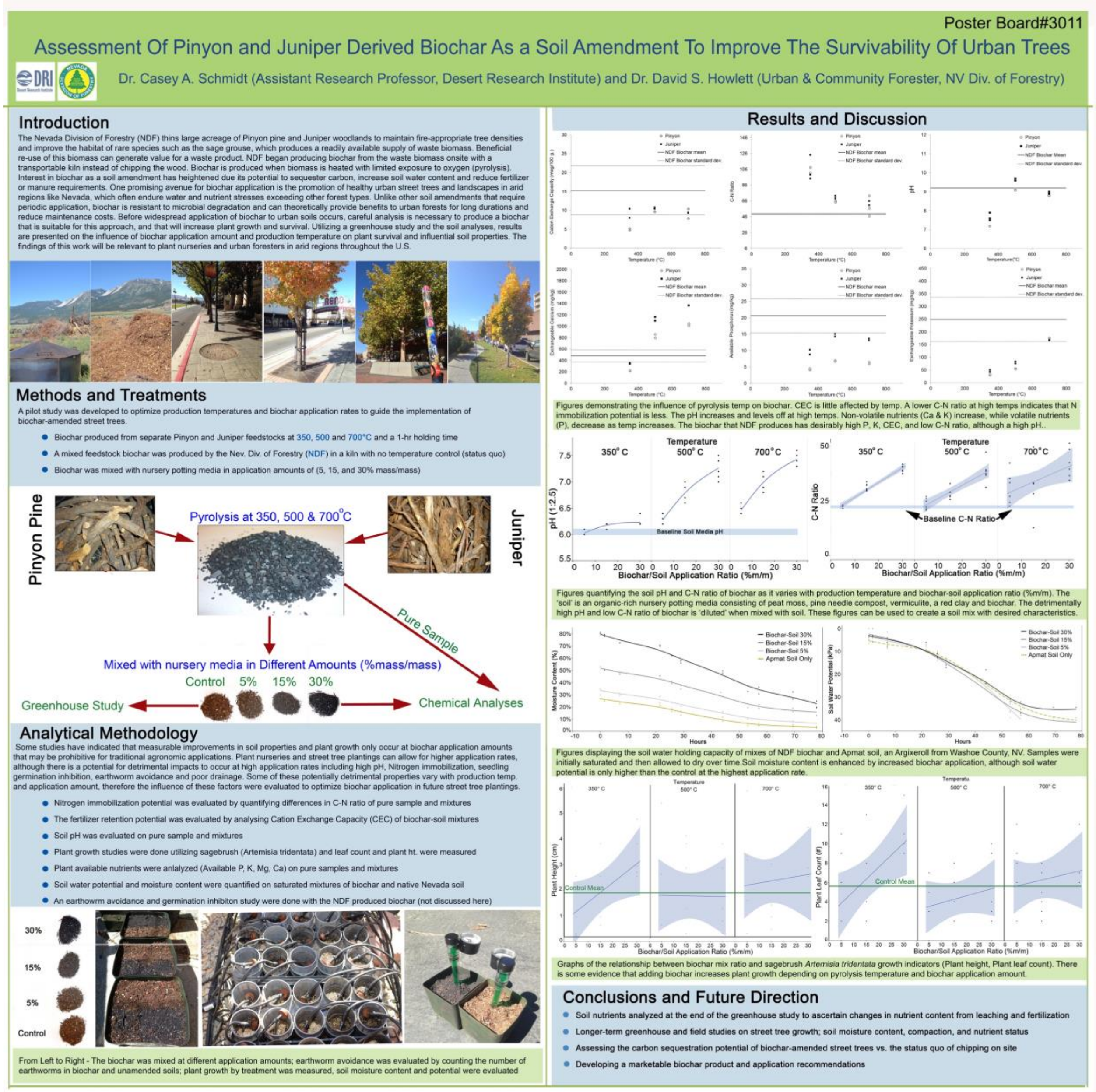
Plant Nutrients

Trees were destructively harvested by removing the tree from the soil and thoroughly rinsing to remove all soil particles. Aboveground and Belowground biomass were clipped, bagged separately, and sent to the lab. Plant nutrients were analyzed by the Oklahoma State University Soils lab using standard methods.

Statistical Analysis

In order to discern if there was a significant linear relationship between biochar amount and particle size as predictors, and the resulting parameter of interest a multiple linear regression was done using least squares regression with block as a random variable. Significant relationships were determined at alpha = 0.10. The control sample had 0% biochar, but no particle size to use in the multiple linear regression so it was compared to the different soil types using standard t-tests at an alpha of 0.05.

Appendix 2: Soil Science Society of America Poster



Appendix 3: Rain Garden Fact Sheet

BIOCHAR-AMENDED RAIN GARDENS

Casey Schmidt
Assistant Research Professor
Desert Research Institute
Casey.Schmidt@dri.edu

The urban areas and roadways that surround Lake Tahoe are a major source of the sediments and nutrients that degrade the lake's clarity. To improve lake clarity and reduce pollutant loading, low-impact development approaches such as installing rain gardens next to primary roads are being implemented. Rain gardens are vegetated stormwater treatment systems that are constructed to increase infiltration in urban areas.

The amended soil used in rain gardens filters stormwater runoff and sequesters sediments, nutrients, oils, and metals. The amended soil also provides essential nutrients and improves the soil's water holding capacity, which promotes plant growth. Developing a soil media that facilitates plant survival in this semiarid region and protects the lake from pollutants is crucial. To further this goal, a biochar amendment was included in the rain garden soil mix.

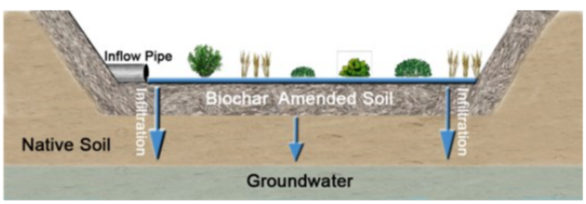


Figure 1. A biochar-amended rain garden. Stormwater and snowmelt runoff from roads is diverted to a rain garden for infiltration where it supplies water to plants and sequesters pollutants.

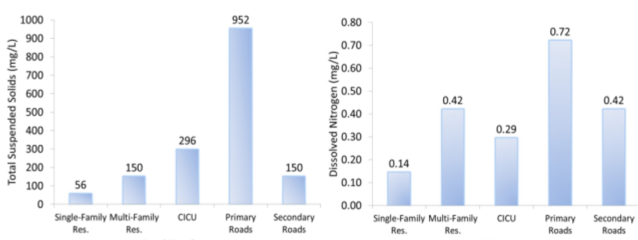


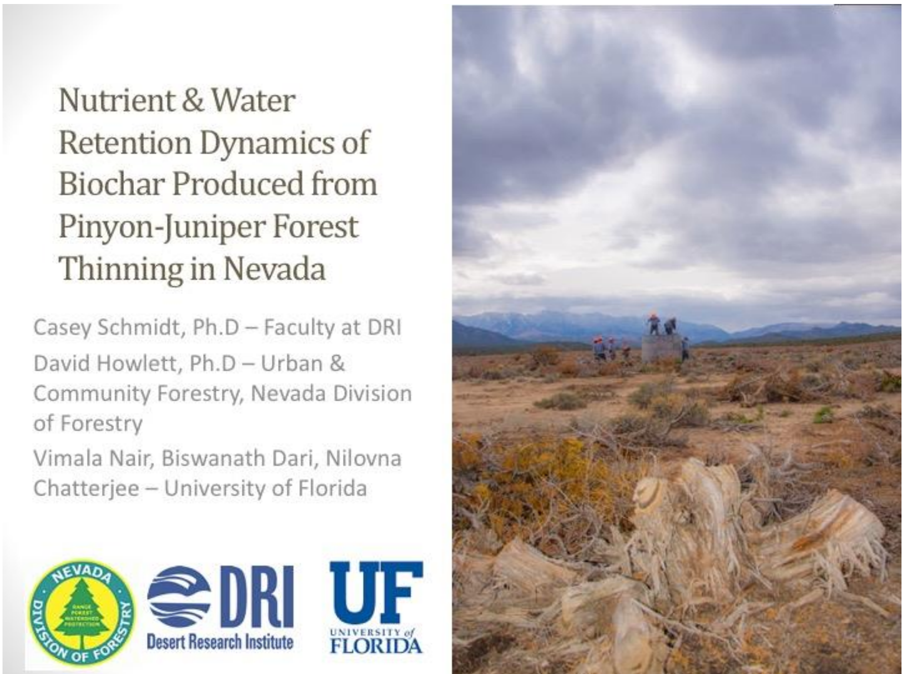
Figure 2. Primary roads are the major source of nitrogen, phosphorus, and total suspended solids (TSS), which are the primary pollutants that degrade Lake Tahoe's water clarity (Lake Tahoe TMDL Technical Report, June 2010).

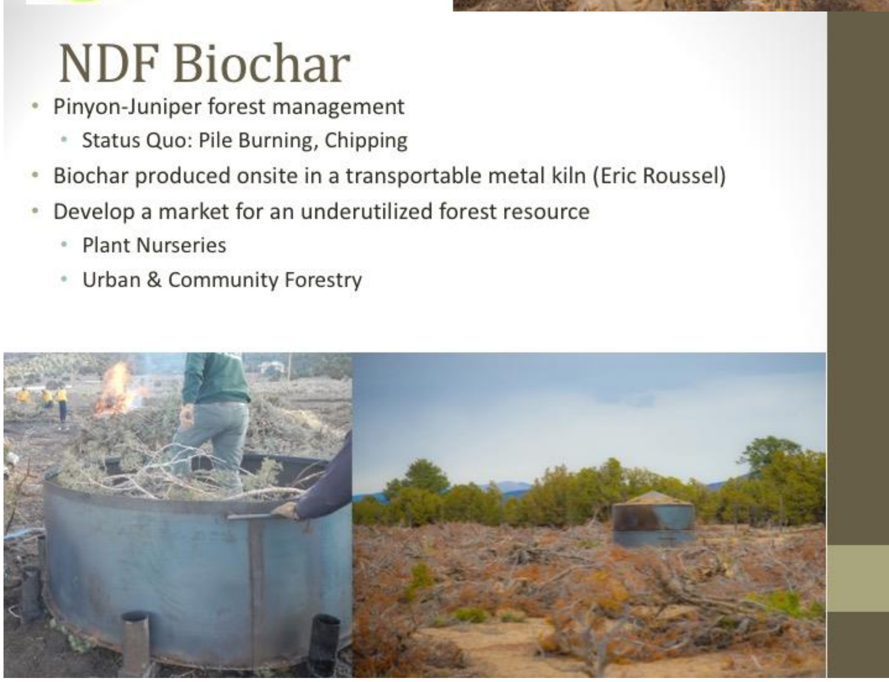
BIOCHAR

Biochar is an organic carbon charcoal that is produced by pyrolysis (heating wood in low-oxygen conditions). The following effects of pyrolysis on wood make biochar a beneficial soil amendment:

- Biochar is resistant to decomposition, so it sequesters and returns essential soil carbon to gardens, landscapes, and restoration sites in a stable, long-lasting form.
- Biochar has a highly reactive surface area that retains nutrients and contaminants in stormwater runoff (similar to the activated carbon in water and air filters).
- Like other organic matter such as peat, manure, and mulch, biochar increases the soil's water holding capacity and promotes plant growth.

Appendix 4: Soil Science Society of America Presentation





Transportable Metal Kiln

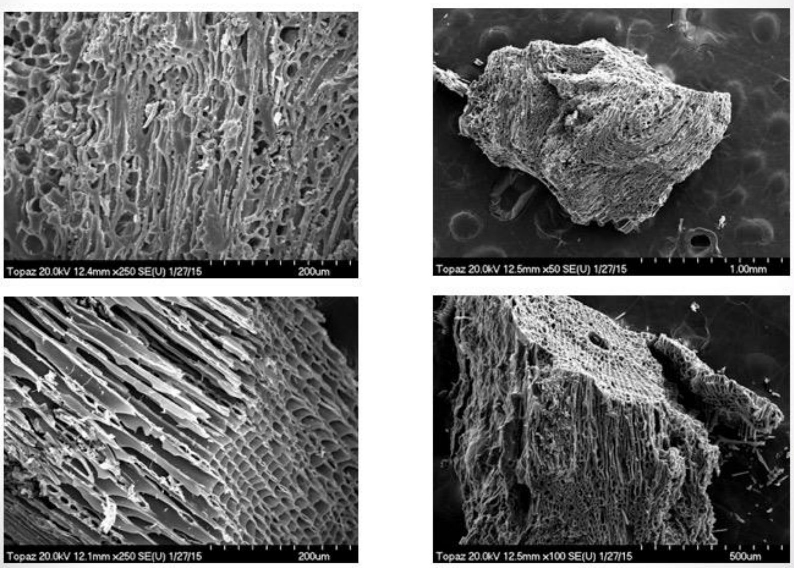
Chimneys and Inlets

Packing the Wood

Lighting the Fire

Sealing the Can

SEM of P-J Biochar



Biochar Production

- Kiln can take 10 cubic yards of relatively tightly packed wood.
- Produce 660 lbs (299 kg) of biochar, and 142 lbs (64 kg) of Carbon produced in a two-day burn
- Wood volume reduced by ~65%, mass reduction 71%
- How to process?

Street Tree Benefits

- Street tree canopy can increase individual housing price by $7,000 (Donovan & Butry, 2004)
- Tree canopy in Las Vegas Valley stores nearly 1,010,055 tons of carbon, provides an annual air pollution removal value of $8.5M and a total stormwater runoff mitigation value of approximately $208M.

Source: Las Vegas Valley Urban Canopy Analysis, 2012-Nevada Division of Forestry (http://forestry.nv.gov/wp-content/uploads/2012/05/LasVegasValley_Canopy_2012.pdf)

Street Tree Mortality

Table 1
Summary of street tree survival rates from available literature. Time period begins with year(s) planted or initially surveyed. Survival rates marked "†" were not included in regression analysis or summary statistics. Survival rates marked "‡" measured survival of already established trees; for all other studies, "survival rate" is survivorship after planting l_t, as defined in the text. When studies reported a range of survivorship and time periods, the minimum estimated annual survival rate was calculated.

Location	Study groups (sample size N_s)		Survival rate (%)	Time period t (yrs)	Estimated annual survival l_{annual} (%)	Source
Oakland,	All species					Sklar and Ames (1985)
CA	W/community participation	(1,500)	~60–70†	~5	90.3	
	W/out community participation	(2,000)	~0.5†	~5–10	34.7	
Oakland, CA	All species	(480)	66	2	81.2	Nowak et al. (1990)
San Francisco,	All species	(1,987)	86.4	5	97.1	Sullivan (2004)
CA		(1,869)	67.9	10	96.2	
IA small towns	All species	(214)	87.0	4–5	96.6	Thompson et al. (2004)
Urbana, IL	All species	(1,768)	4.4†‡	50	n/a	Dawson and Khawaja (1985)
Boston, MA						Foster and Blaine (1978)
Beacon Hill	All species	(215)	39†‡	10	n/a	
Beacon St.	*Tilia* spp.	(350)	23	66	97.8	
Boylston St.	All species	(136)	74	2–4	86.0	
Syracuse,	*Acer platanoides* L.	(unk.)	75.0†‡	27	n/a	Richards (1979)
NY	*A. saccharinum* L.		75.0†‡		n/a	
	A. saccharum Marsh.		47.0†‡		n/a	
	Gleditsia triacanthos L.		30.0†‡		n/a	
OH						Sydnor et al. (1999)[a]
Cleveland	*Liquidambar styraciflua* L.	(68)	64.7	45	99.0	
Cleveland	*Acer pseudoplatanus* L.	(65)	29.2	42	97.1	
Cleve. Area	*Prunus serrulata* Lindl.	(50)	0	41	–	
Cleve. Area	*Betula pendula* Roth	(53)	0	40	–	
Cleveland	*A. rubrum* L.	(57)	87.7	39	99.7	
Cleve. Area	*Crataegus phaenopyrum* Borkh.	(50)	2.0	38	90.2	
Columbus	*A. platanoides*	(84)	46.4	38	98.0	
Toledo	*A. platanoides*	(80)	56.3	34	98.3	
Toledo	*A. platanoides*	(71)	15.5	32	94.3	
Cleve. Area	*G. triacanthos*	(76)	92.1	30	99.7	
Philadelphia,	All species	(50)	84.0	2	91.7	
PA		(571)	93.5	1.5	95.6	
		(705)	93.3	1	93.3	
PA & MD small towns	*Malus* spp.	(unk.)	94–100	3	98.0	
WI						
Milwaukee	All species	(1,003)	58.8	4–6	87.6	
Waukesha		(677)	76.5		93.5	
Stevens Point		(368)	74.9	4–9	93.0	
Milwaukee,	All species			10		
WI	Damaged by constr.	(432)	77.3		97.5	
	Undamaged	(413)	81.4		98.0	
Northeastern US cities		(1,333)	93.3†	(standing dead trees)	n/a	
Brussels,	All species, newly planted	(2,300)	93.5	1	93.5	
Belgium		(3,710)	89.7	1	89.7	
		(3,148)	80.3	1	80.3	
		(2,463)	91.3	1	91.3	
	All species, existing	(75,653)	97.2†‡	1	n/a	
		(80,493)	97.4†‡	1	n/a	
		(82,374)	96.8†‡	1	n/a	
		(81,581)	98.1†‡	1	n/a	
Beijing, China	All species	(750)	25.1	0.25	0.4	
North England cities	All species and towns	(unk.)	90.3†	(unk.)[b]	n/a	

[a] For Sydnor et al. (1999), only planting cohorts with ≥50 trees were included.
[b] For Gilbertson and Bradshaw (1985), time period was reported as "newly planted", and survival rate reflects percent of live trees among those encountered.

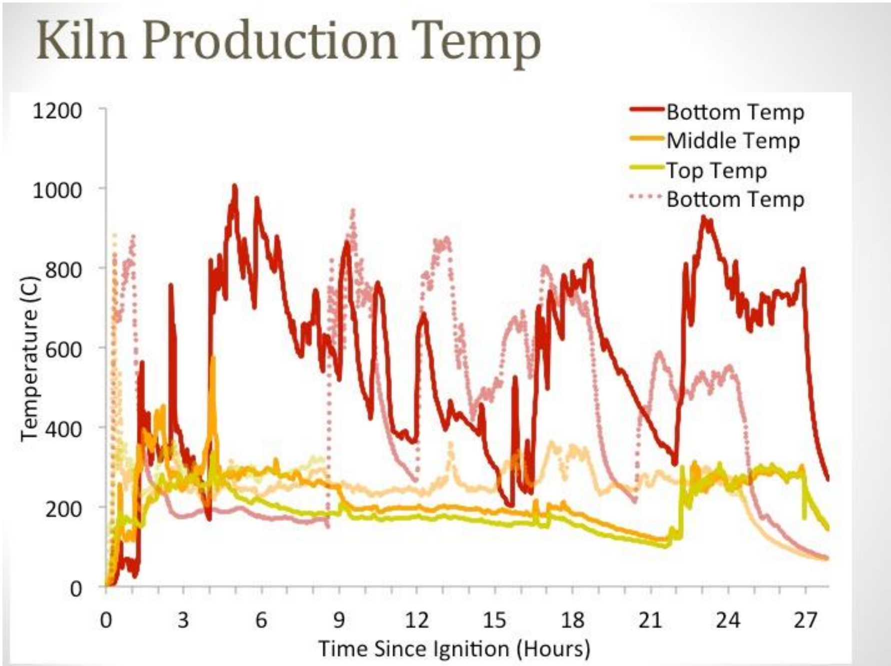
Roman and Scatena, 2011 - Street tree survival rates: Meta-analysis of previous studies and application to a field survey in Philadelphia, PA, USA

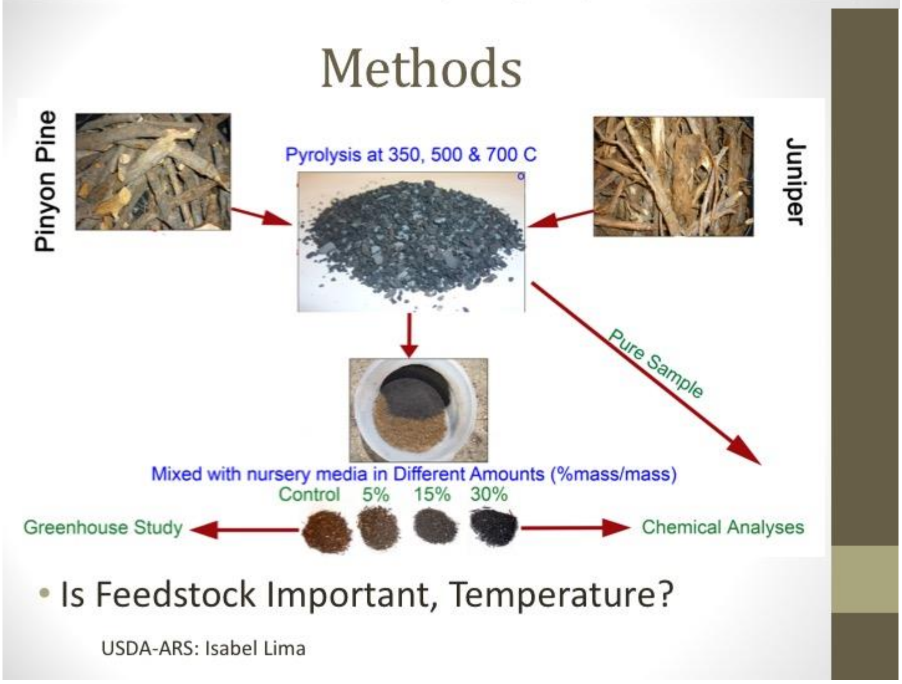
NDF Nursery Application

- Initial hazard assessment: Is it harmful/beneficial to plants, soil organisms
  - What application rates/How much to add?
  - Do production conditions matter: **Temperature**, transportable metal kiln vs. carefully controlled production conditions
- Guide future biochar applications and projects applicable to urban forestry

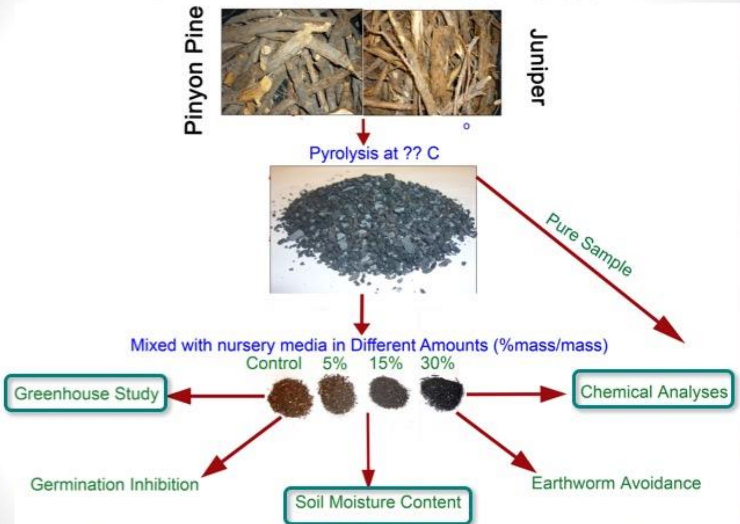






Kiln Production Temp
Bottom Temp
Middle Temp
Top Temp
Bottom Temp
Temperature (C)
1200
1000
800
600
400
200
0
0
3
6
9
12
15
18
21
24
27
Time Since Ignition (Hours)

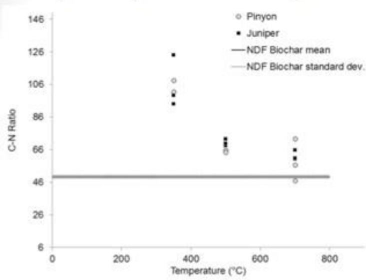

Methods
Pinyon Pine
Pyrolysis at 350, 500 & 700 C
Juniper
Pure Sample
Mixed with nursery media in Different Amounts (%mass/mass)
Control 5% 15% 30%
Greenhouse Study
Chemical Analyses
• Is Feedstock Important, Temperature?
USDA-ARS: Isabel Lima

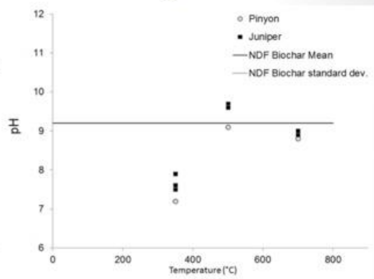
NDF Biochar Methods



- How does NDF biochar compare?

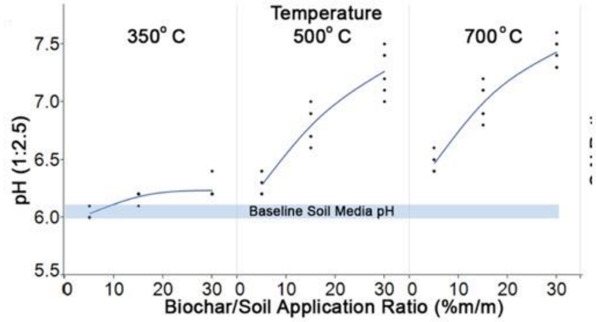
Pyrolysis Temp. vs. Soil Properties





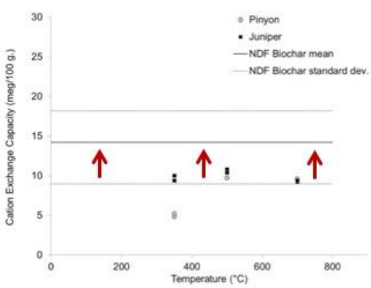
- pH increases with pyrolysis temperature; C-N ratio decreases
- NDF Biochar has desirable CEC, C-N Ratio, albeit high pH

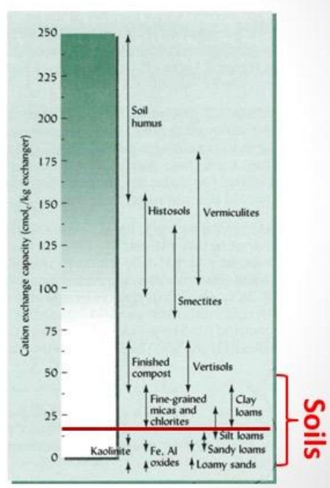
Alkalinity and N immoblization of Biochar Mixtures



- What affect will high pH have on alkaline NV soils, urban soils
- Soil-Biochar mixtures tailored to soil type

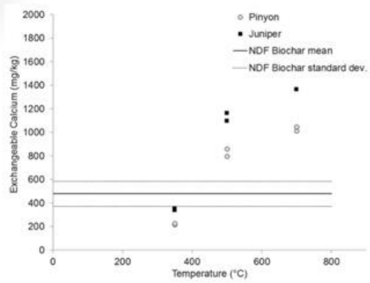
Cation Exchange Capacity

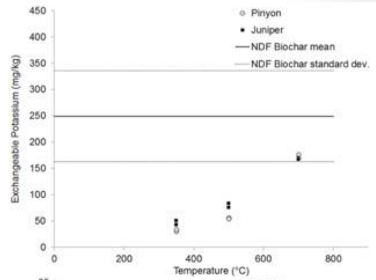




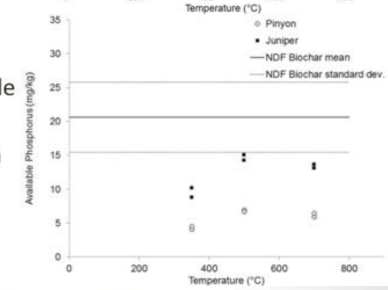
- Moderate CEC increase for mineral soils
- NDF Biochar

Pyrolysis Temp vs. Plant Nutrients

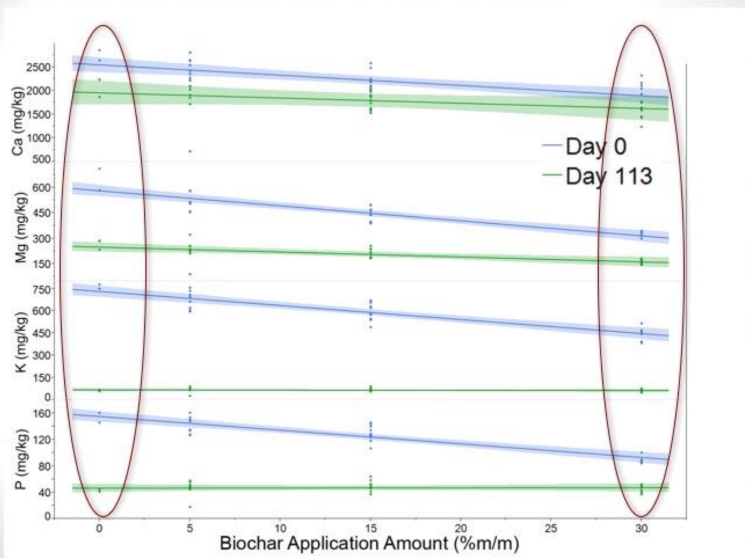


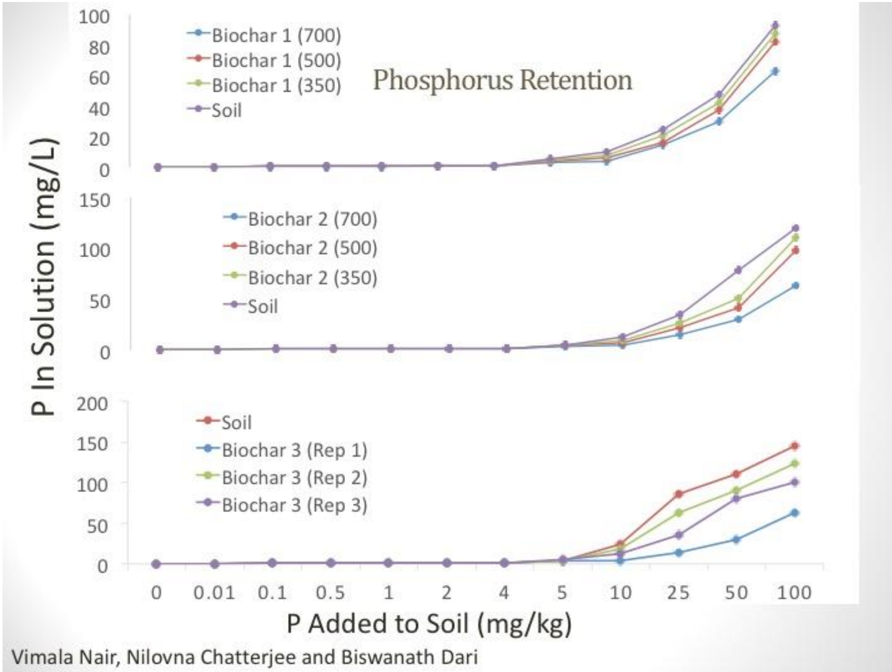


- Non-volatile nutrients increase with temp (e.g. Ca, Mg, K), volatile nutrients stabilize (e.g. P)
- NDF Biochar has high K, P, low Ca

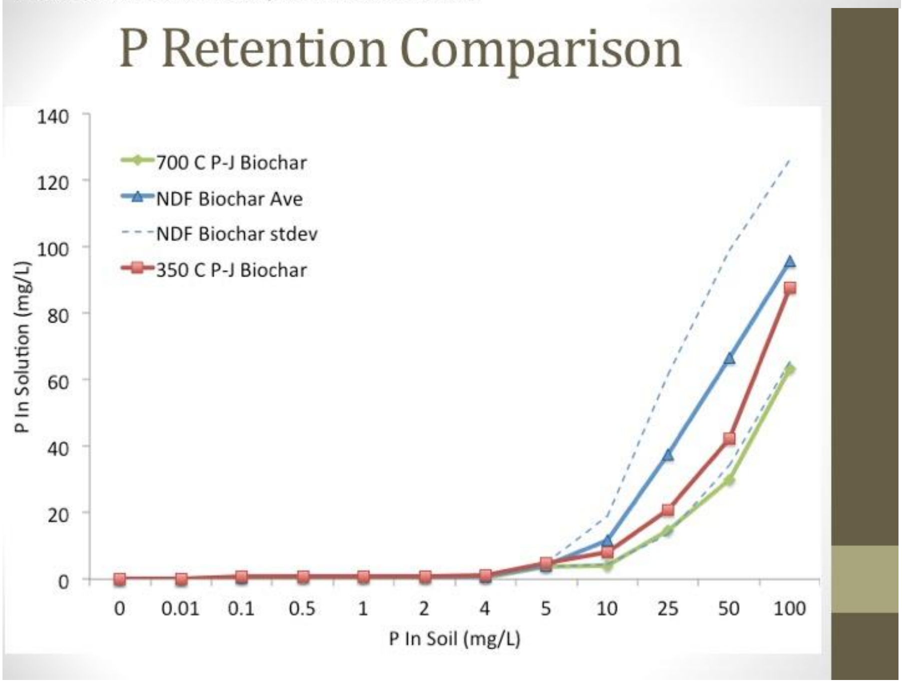


Soil Nutrients Over Time



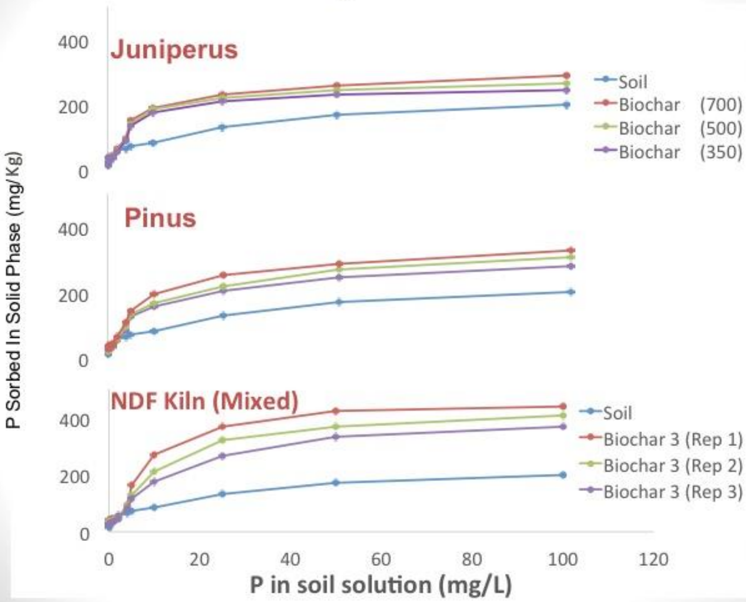


Phosphorus Retention
Biochar 1 (700)
Biochar 1 (500)
Biochar 1 (350)
Soil
Biochar 2 (700)
Biochar 2 (500)
Biochar 2 (350)
Soil
Soil
Biochar 3 (Rep 1)
Biochar 3 (Rep 2)
Biochar 3 (Rep 3)
P In Solution (mg/L)
P Added to Soil (mg/kg)
0 0.01 0.1 0.5 1 2 4 5 10 25 50 100
Vimala Nair, Nilovna Chatterjee and Biswanath Dari



P Retention Comparison
700 C P-J Biochar
NDF Biochar Ave
NDF Biochar stdev
350 C P-J Biochar
P In Solution (mg/L)
P In Soil (mg/L)
0 0.01 0.1 0.5 1 2 4 5 10 25 50 100

Max P Sorption

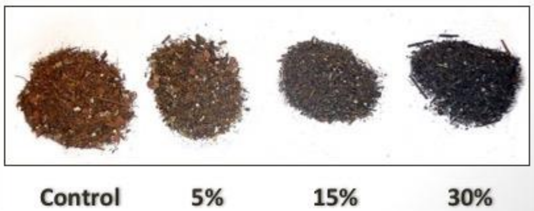


Soil Studies Conclusions

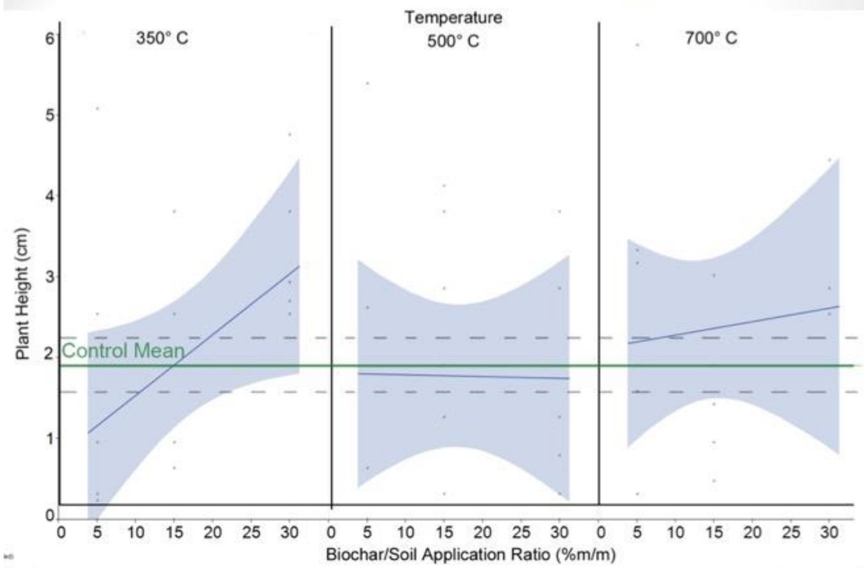
- P-J Biochar is not a fertilizer
- Potential enrichment of P in biochar
- NDF biochar has a high pH, but also high cation exchance capacity, high phosphorus, high Potassium and compares favorably to the other biochar types.

Greenhouse Study

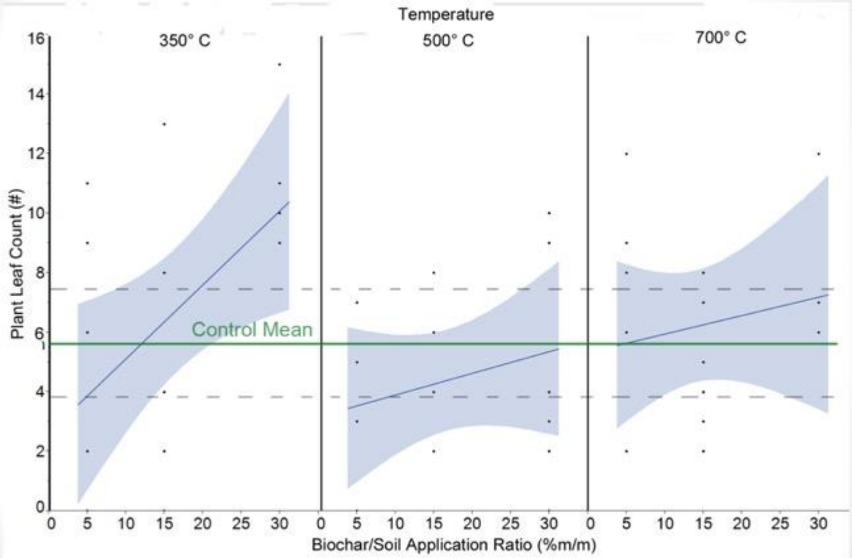
- Sagebrush (*Artemisia tridentata*) is the indicator species used.
- Germination Study



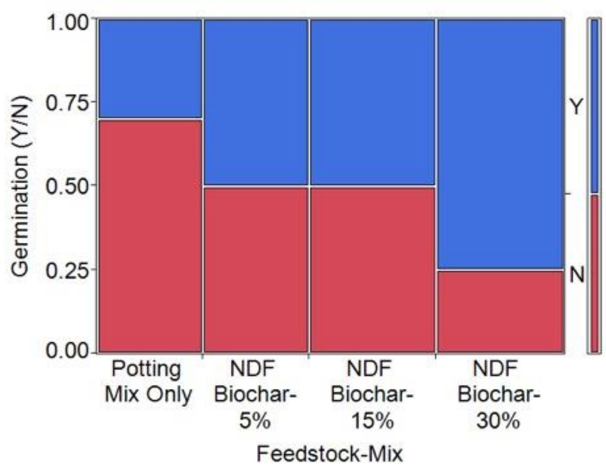
Plant Growth: Height



Plant Growth: Leaf Count



Germination Inhibition Study



- Nasturtium and Morning Glory
- No significant difference in 'Time to germinate' between treatments

Plant Available Water – NDF Potting Media

- Evaluate plant available water to tailor nursery irrigation of biochar mixes/street tree growth

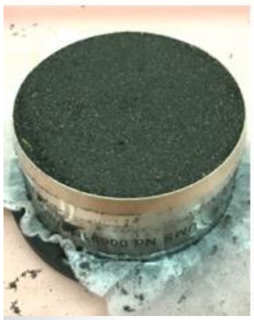
NDF Potting Media Components

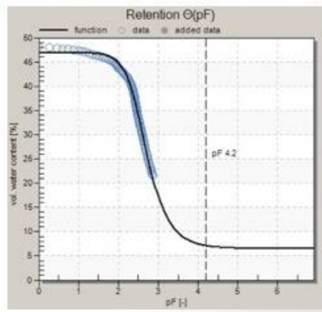
- 4 Parts Composted Fir Bark
- 4 Parts 'Old Soil'
- 1 Part Peat Moss
- 1 Part Vermiculite
- 1 Part Perlite
- 1 Part Rice Hulls

How to Process Biochar

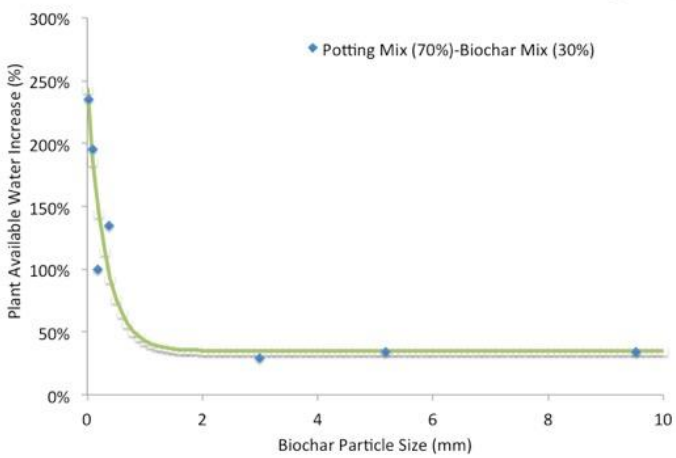
Analysis Procedure

- Pack soil mixtures consistently
- Saturate soil mixtures
- Simplified Evaporation Method
- Measure moisture content over time.
- Measure water potential at two depths within the soil
- Fit curves with van Genuchten-Mualem model



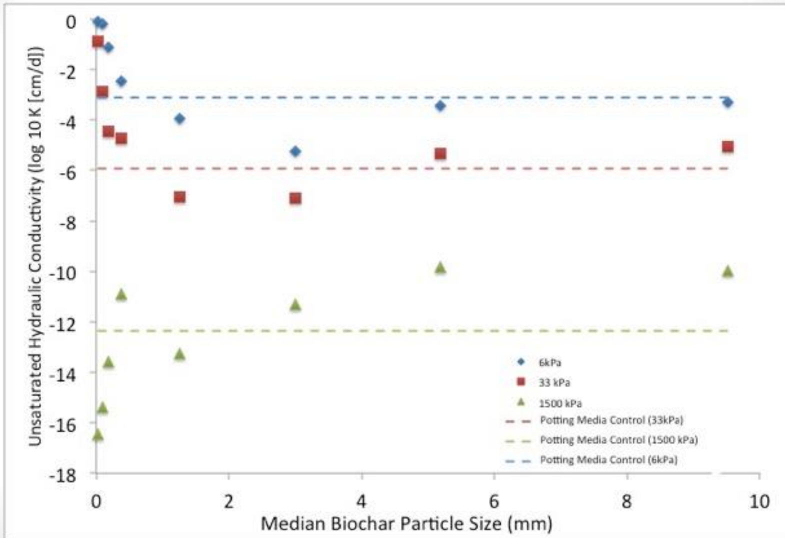


Plant Available Water NDF Potting Soil



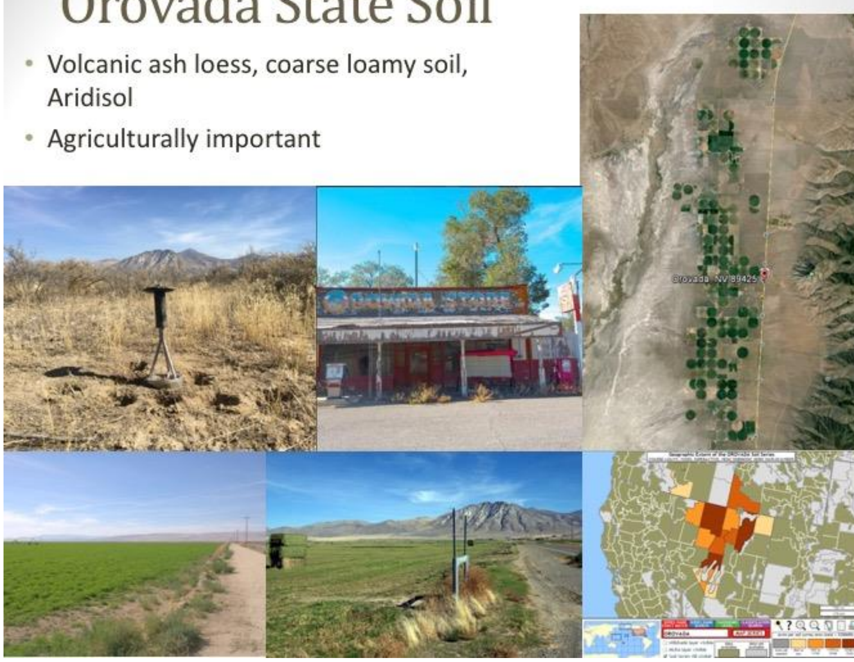
- Adding Biochar to the NDF Nursery Potting Media more than doubled plant available water in fines (234%) to an increase of over one-third (36%) in coarse.
- Biochar greater than 2 mm had equivalent PAW

Unsaturated Hyd. Cond/Drainage



Orovada State Soil

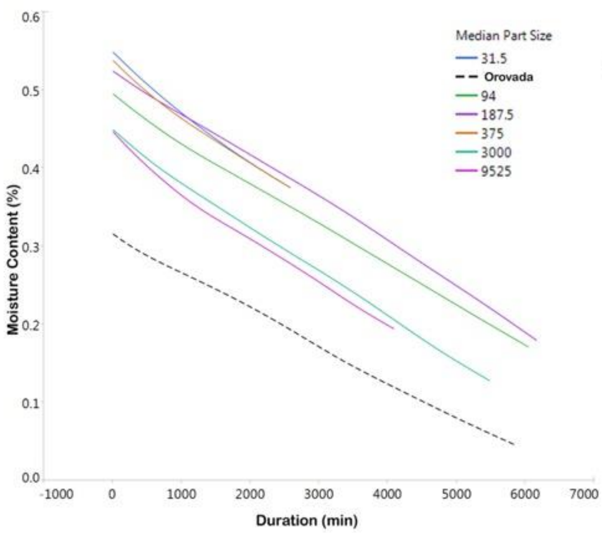
- Volcanic ash loess, coarse loamy soil, Aridisol
- Agriculturally important

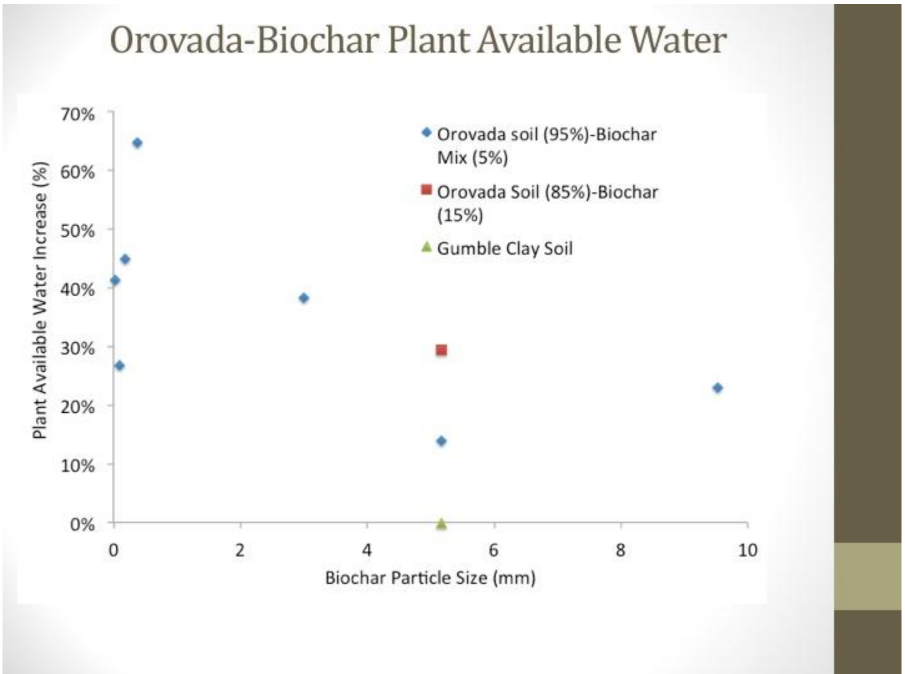


Orovada Mixes

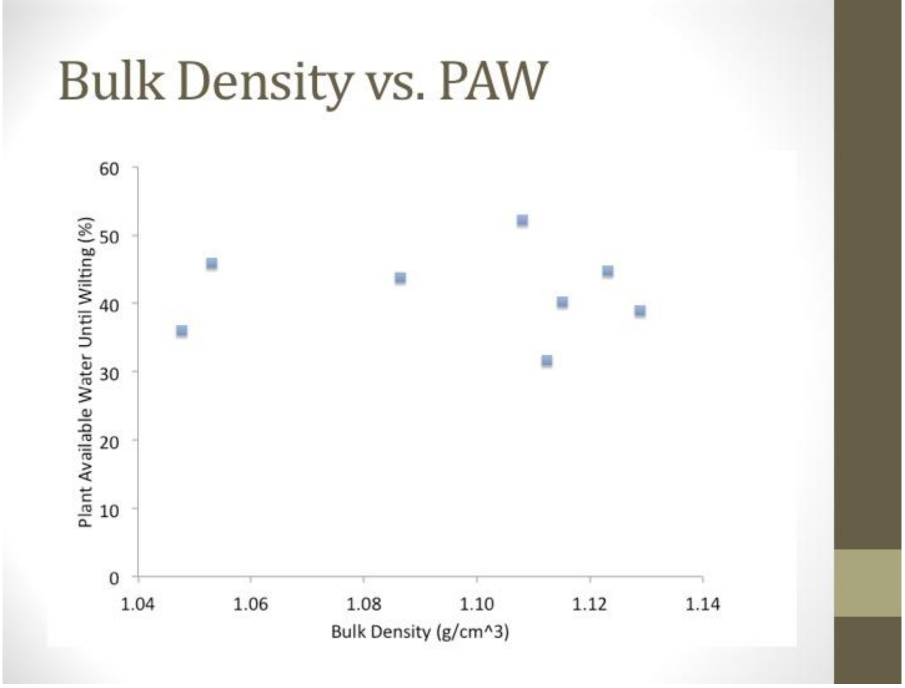
0.063 -0.125 mm   0.250-0.500 mm

Soil Moisture Content – Orovada Soil





Orovada-Biochar Plant Available Water
Orovada soil (95%)-Biochar Mix (5%)
Orovada Soil (85%)-Biochar (15%)
Gumble Clay Soil
Plant Available Water Increase (%)
Biochar Particle Size (mm)



Bulk Density vs. PAW
Plant Available Water Until Wilting (%)
Bulk Density (g/cm^3)

Biochar Expansion

- Genoa Trees commercializing composted biochar
- Large-scale rangeland restoration in Ely, NV (NDF, ENLC, USFS)
  - Soil amendment benefits of biochar
  - Appropriate technology
  - 10 kilns!


Moving Forward

- Carbon mass balance (wood in➔biochar, pyrolysis oil, smoke
- Measure NOx, SOx, CO, CO_2, CH_4, HC, O_2 in real-time
- Measure PM 2.5 to PM 10, VOCs in real-time.
- Canister samples to analyze for C2-C12 and above gasses.
- Energy content, water content, and component analysis of pyrolysis oil.
- Life Cycle Analysis comparing biochar production to catastrophic wildfires, pile burning, chipping.